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DEPARTMENT OF TRANSPORTATION
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OFFICE OF TRANSPORTATION MATERIALS AND RESEARCH

Speed Profiles and Fuel Consumption Relationships

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16. Abstract

Over 2 million individual readings on fuel consumption, traffic volume, speed, grade, acceleration and deceleration rate, and other related traffic data were collected. These data were extensively edited, "cleaned up", and reduced to a coherent (link) data base of 8575 records of 23 data fields each. Questionable data were marked and error codes were added so that the data set is of known reliability. Empirically-gathered fuel consumption values for two 1980 Citations are provided along with VEHC computer generated values for a 1982 Citation and a computerized representation of the 1986 passenger vehicle fleet. This data base is available to other researchers. The computer-generated fuel values are based on the VEHC program, which is the same computer model used by NETSIM and other traffic programs.

The ratio of the VEHC program Citation fuel prediction to the empirically gathered Citation fuel data ranged from 1.156 to 3.905 for this link data base. The average fuel ratio changed substantially at different grades and acceleration rates, raising questions regarding the applicability of using the VEHC model for fuel consumption studies of congested traffic conditions. The most fuel efficient speed under congested driving conditions was approximately 30 mph for the computer model fleet vehicle, while it was measured at approximately 50 mph for the 1980 Citations.

The data collection and analysis techniques developed for this project directly resulted in the implementation of a computerized traffic congestion monitoring system now being used throughout California.

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1. OBJECTIVE

The overall objective of this project was to gain a better understanding of the relationships between traffic speed, volume, and fuel consumption for congested freeway conditions. This was done by using computerized data collection equipment to gather large quantities of information and correlating this empirical data with the output of the vehicle fuel consumption prediction model VECH. The secondary objective was to use these data to validate the computer program VECH.

The methodology used in this research effort are more empirical than theoretical. It was not our intention to develop or modify a new fuel consumption model, only to test the validity of existing ones. We have gathered millions of pieces of raw data, using computers to manage and statistically analyze this information. These data have been reduced to a coherent data base capable of further validation of theoretical models.

These objectives represent a much more narrow focus than was intended at the inception of this project. The original project proposal suggested that we would attempt to gather enough data to produce statistically significant energy factors for a wide range of driving conditions: grade, slowdowns, operational improvements, etc. After extensive discussion with Mr. Albert Santiago, FHWA Highway Research Engineer, the original objectives were pared down to a more reasonable size. This restructuring of the objectives was the primary reason for a major rewriting of the project proposal in 1985.

1.1 BACKGROUND

Some preliminary work was done on urban arterial signal timing as part of the early 1982 proposal. Part of the funding for this work was paid for by the Fuel Efficient Traffic Signal Management (FETSIM) Program, and an independent report was generated. The results of this were largely inconclusive because, apparently, the signal timing optimization computer model was not run correctly by the city where the evaluation was performed. A copy of this report is shown in Appendix A.

Some conclusions were generated from this early study that helped guide further progress of this project:

1) We concluded that a minimum of a few megabytes of data needed to be collected to assure statistical validity in the parametrically "noisy" environment of real traffic conditions.

2) These data require extensive analysis and editing for data dropouts, transducer nonlinearity, irregular file length, operator error, and other problems associated with real data collection.

3) The only way these large volumes of data with error checking can be collected is through the use of computer technology. The capabilities made available through the use of these computers are readily apparent throughout this report.

1.2 LITERATURE SEARCH

The relationship between vehicle fuel consumption and speed has been the subject of controversy for many years. Studies started in the early 1950's using instrumented vehicles indicated that there was a positive correlation between fuel consumption and traffic conditions (1), but did not precisely delineate this relationship.

The most well known of these early studies was done by Paul Claffy in 1971 (2). This researcher used five vehicles to determine the fuel consumption and other operational costs for both constant speed and isolated acceleration conditions. His findings indicated that the minimum fuel consumption rate for an "average passenger vehicle" occured at around 30 mph (Figure 1). This study was done under controlled conditions for constant speed, and although these conditions are not indicative of real on-the-road conditions, the conclusion that 30 mph yielded the best fuel consumption was used by many traffic engineers throughout the 1970's.

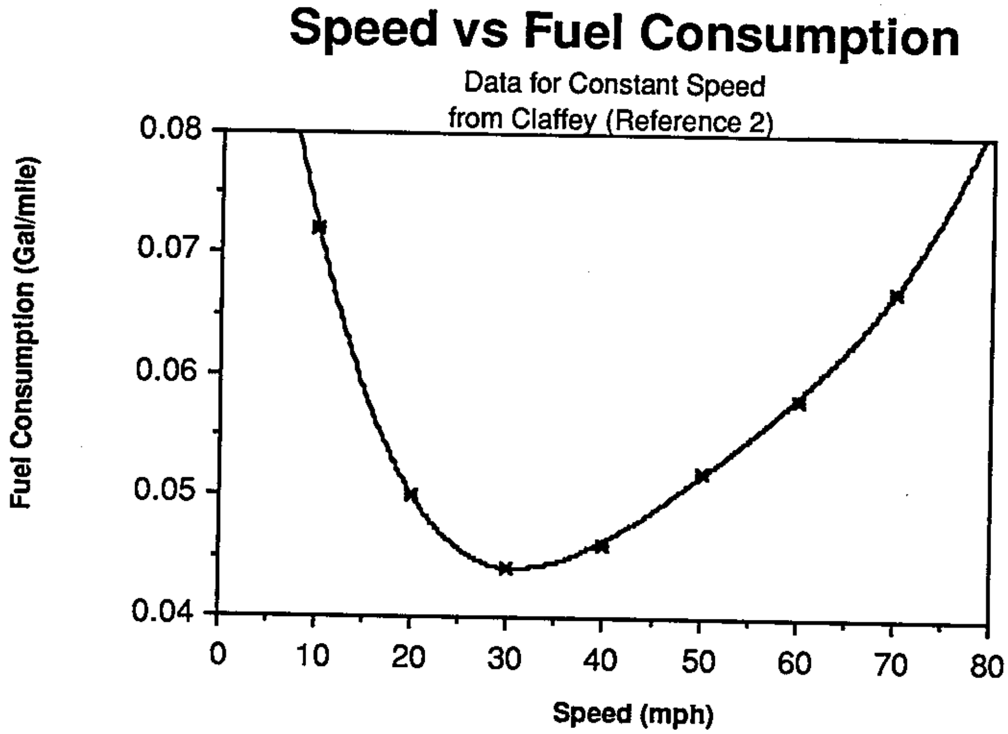

FIGURE 1

The Claffy report was largely superseded by a second FHWA sponsored study by Zaniewski et al (3). This report derived constant speed fuel consumption rates as a function of grade for a number of different vehicle types. The report also included findings on the fuel consumption for acceleration/deceleration between any set of speeds. Using this data it is theoretically possible to determine the fuel consumption for any driving scenario (series of constant speed and accel/decel cycles). This capability has been implemented in the Caltrans program HEAP based on Zaniewski data (4).

A slightly different approach to fuel consumption was taken by Evans in 1977 (5). He concluded that fuel consumption could be calculated by the function A + B(t), where (t) is the total travel time between any two points. This relationship was largely confirmed by Wagner (6) in 1980 for a number of different passenger cars. It shows that fuel consumption is inversely proportional to speed, so the lowest fuel consumption is at the fastest speed. Unfortunately, this relationship was derived only at relatively low speeds (<40 mph) for urban city driving conditions and has not been proven for other driving conditions. Nevertheless, it has been used widely in energy studies throughout the 1980's.

A number of more involved fuel consumption models have been proposed based on Evans' 1977 work. Watson et.al. (7) added a few terms to the Evans' equation finalizing on the relationship:

$$FC = k_1 + k_2/\overline{V} + k_3\overline{V} + k_4\left(\frac{\Sigma(\Delta V)^2}{D}\right)$$

where FC is the fuel consumption rate, k_1, k_2, k_3, and k_4 are empirically derived constants, $\overline{V}$ is the average speed for any trip of distance D, and ΔV is the difference between the trips highest and lowest speed. This relationship is reported by authors as being valid for virtually any driving cycle and has the advantage of being easily derived from a simple mechanical tachograph. All that is needed are the highest, lowest, and average speeds and the distance for any trip *. The last term in the above equation is the Positive Kinetic Energy (PKE) and has found its way into a great many Australian research efforts around the early 1980's (8).

There have been a number of attempts at extending the Evans model by the U.S. academia as well. A joint effort of Stanford and UCB (9) yielded the relationship:

$$FC = (9.58 \times 10^{-6}\, W + T/45) \times (0.120296/T + 684.939\, T - 9930.1\, T^2 - 14.7304)$$

where FC is the fuel consumption rate (gal/mi), T is the trip travel time (hr/mi) and W is the weight of the vehicle (lb). Despite the elegant nature of the above equation, it has yet to receive wide acceptance in the traffic engineering field.

The most recent major effort in the fuel consumption field was done by McGill in 1985. (10) This was a comprehensive study of the 15 passenger vehicles and pickups that were chosen to be most representative of the U.S. vehicle fleet in the near term future. Each of these 15 vehicles was tested on a dynamometer to determine the fuel consumption as a function of engine RPM and torque. The vehicles were also road tested to determine the relationship between vehicle speed and

* We tested this method in the early stages of our research and found it not to yield a high correlation with the measured fuel consumption rate for actual highway conditions.

acceleration rate with engine RPM, torque, and transmission gear. Combining these two data bases by computer, it is possible to determine the fuel consumption rate for any combination of speed and acceleration that any of the 15 vehicle types were capable of performing. Grade can be modeled by changing the effective acceleration - and thereby torque - experienced by the vehicle.

This method has been entirely automated by use of the VEHC program. This program uses the above data base to determine the total fuel consumption for any combination of the 15 vehicle types under any driving scenario. The driving scenarios must have the instantaneous speed and acceleration for the vehicles each second (i.e. VEHC uses a one-second time step). Also, a continuous section of roadway grade must be specified, so that VEHC knows the instantaneous grade for every second the vehicles are traveling. VEHC also compensates for ambient temperature.

It is this model, VEHC, that is the subject of a substantial portion of the analysis of this report. The output from this computer model and data base will be compared with real fuel consumption data gathered under actual congested freeway operating conditions.

2. INSTRUMENTATION

The vehicle instrumentation used in this study was originally designed and configured in 1979 by a private consultant. It was used for a California Energy Commission study on fuel consumption and signal timing. We inherited this equipment from the Energy Commission.

This data collection system was state of the art when it was developed. It used data collection instrumentation interfaced to a data logger with a unique digital tape spooling technique that allowed all of the data collected to be retrieved from a single channel digital tape drive. Unfortunately, over the years the system had aged considerably and almost every component failed at one point or another during this study. The unreliability of the old system led Caltrans researchers to develop a completely new, more versatile system for use in congestion and roadway inventory studies. This system is now used throughout the California Department of Transportation and has provided significant cost savings. It is described in detail in Appendix B.*

2.1 VEHICLES

The vehicles used for this study were two identically configured 1980 Chevrolet Citations. Both used 4-cylinder 151-CID engines with conventional (fuel bowl) carburetors and 3-speed automatic transmissions. In this report, the vehicles are distinguished from each other by their color. One was silver and the other was brown.

2.2 FUEL

We used a Fluidyne model 1228 fuel flow rate indicator and model 1213F fuel flow transducer with temperature sensor for fuel measurement (Figures 2 and 3). This is a reciprocating-piston positive-displacement type meter, meaning that every unit of fuel must positively displace a volume in a cylinder. It is both highly accurate and quite linear over a large range of flows. These properties differentiate it from a less expensive turbine or pitot tube meter. This meter comes with a vapor eliminator to reduce the nonliquid components of the fluid stream before measurement.

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* This is a preliminary copy of a users manual developed for this system. This manual is based on a paper presented at the ASCE Microcomputers in Transportation Conference in San Francisco, California on June 23, 1989.

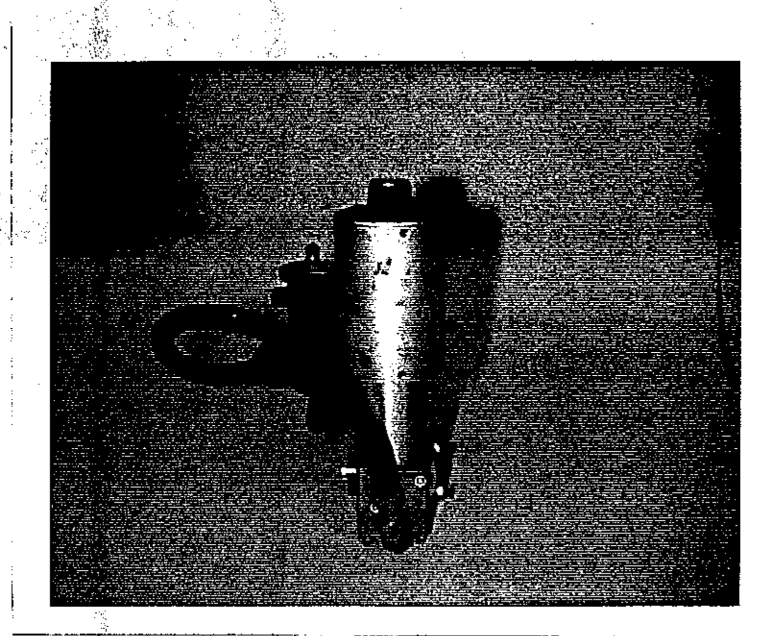


Figure 2, FLUIDYNE FLOW METER TRANSDUCER UNIT, MODEL 1213F.

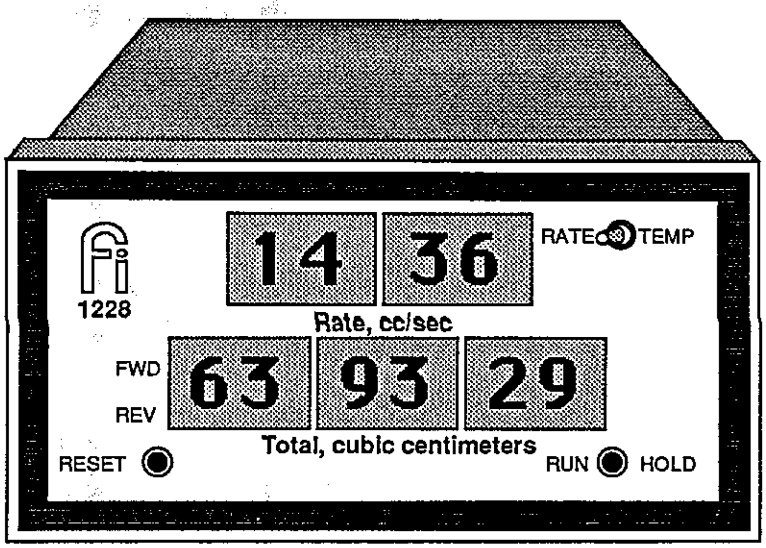


Figure 3, FLUIDYNE FUEL FLOW RATE INDICATOR/TOTALIZER, MODEL 1228.

We also installed an in-line fuel radiator to help reduce the fuel temperature below the vapor point. The fuel meter is temperature-compensated for volumetric expansion, so it produces an output proportional to the true mass flow rate rather than simple volumetric flow rate. A pulse generator attached to the meter outputs one pulse for every 0.10 ml of fuel throughput.

This fuel meter measures the fuel immediately before it enters the carburetor fuel bowl. The fuel meter does not directly indicate the rate of fuel being consumed by the engine. Due to the buffering effect of the fuel bowl and fuel sloshing around in the fuel bowl, there is a 1 to 3 second delay between the time the fuel is measured and when it is consumed. This delay does not allow a real time instantaneous assessment of the fuel being consumed by the engine, so the fuel consumption measurements are only accurate for long-term averages, of at least 15 or 20 seconds. This fact must be taken into account when interpreting the fuel consumption data.

The pulse output and temperature readings are fed into a totalizer that actually does the temperature compensation. A calibration coefficient can be set to allow for different gasoline densities. This totalizer can display the instantaneous fuel consumption rate, cumulative fuel consumption, or fuel temperature.

2.2.1 FUEL MEASUREMENT CALIBRATION

To insure and verify the accuracy of the fuel measurement system, a series of calibrations and standard tests was performed. These evaluations were conducted both before and after data collection. In addition to verifying data accuracy, these tests allowed the fuel data to be related to the Environmental Protection Agency (EPA) fuel consumption values for a 1980 Citation.

Five types of tests were performed on the Fluidyne fuel meters. These tests were:

1) The 1975 Federal Testing Procedure (FTP) fuel economy tests performed by California Air Resources Board (ARB).

2) The EPA Highway Fuel Economy Test Cycle performed by the ARB.

3) Volume calibration test where a known volume was run directly through the meter.

4) Weight calibration test performed with the vehicle running.

5) Manufacturer calibration.

Both Fluidyne meters were returned to the manufacturer for routine recalibration twice during the project. These calibration checks occurred in February 1982 and March 1985 prior to the Redwood City and Los Angeles/San Diego data collection phases. The recalibrations were independently checked using the procedures outlined below.

Both research vehicles were tested by the ARB at their El Monte, California test facility. This facility conducts air quality research and routinely performs emissions testing for purposes of certification and data collection.

Our vehicles were transported to the ARB site on two separate occasions. The first was in November 1983, prior to being used in the FETSIM project in Redwood City, and the second occurred in March and April 1985.

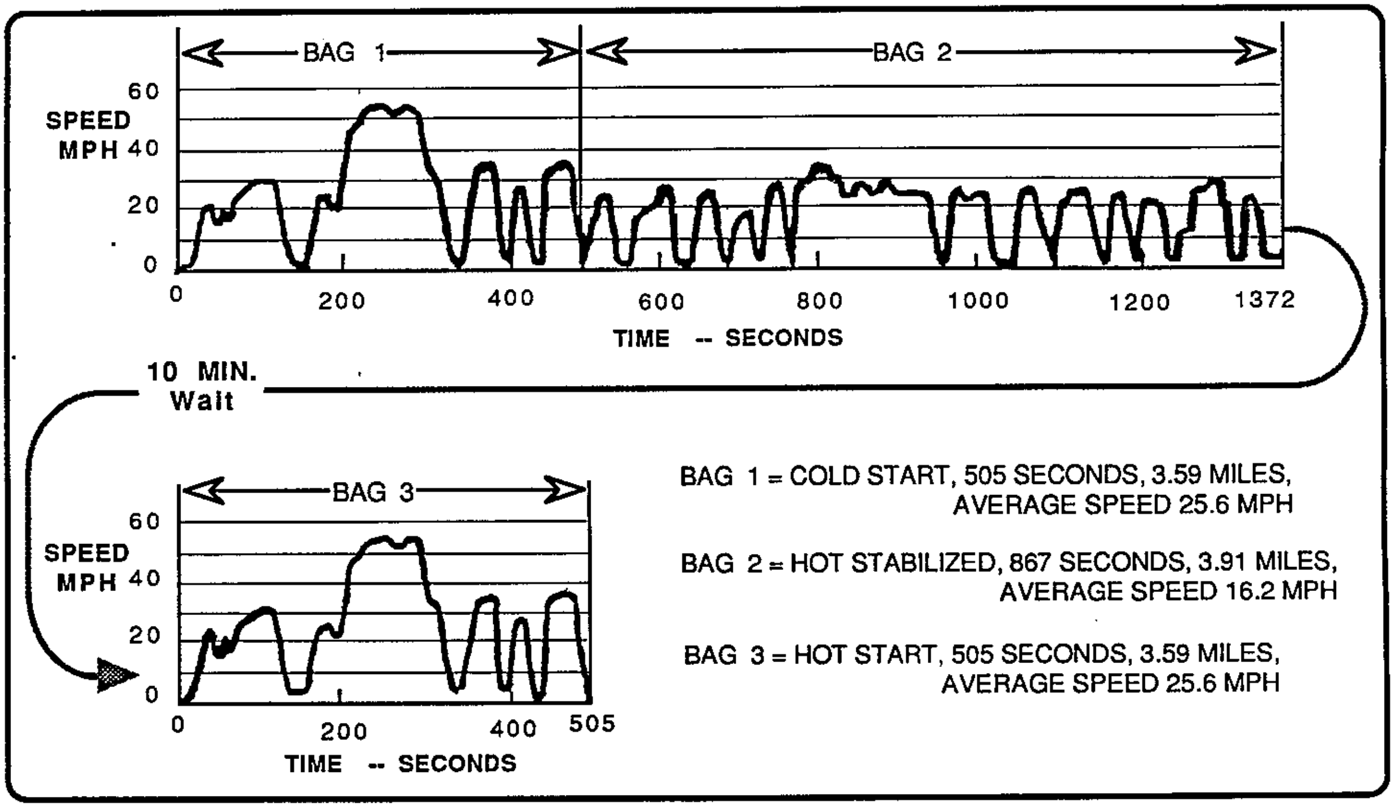
Both tests conducted by ARB (i.e. the 1975 FTP and the EPA Highway Fuel Economy) were performed by running the vehicles on a dynamometer through a standardized driving cycle and collecting all exhaust emissions. Emissions were collected in "bags" and later analyzed by a carbon balance technique to estimate the equivalent amount of fuel consumed. A total of three tests were generally run on each vehicle for each test type, although only two tests were run on one vehicle during the 1985 testing due to a lack of available manpower. Examples of the driving profile for each test type are shown in Figure 4.

The research vehicles were equipped with a complete time-distance-fuel data logging system. Independent data on fuel consumption and driving profiles were collected concurrently with ARB. This data provided the ability to relate our fuel data with the EPA fuel consumption data base. In addition, it gave us an estimate of our data repeatability.

In general, both ARB and our own results showed a ± 1% repeatability for the highway cycle, which was the test of primary interest. Their FTP test results were very close to the 22 MPG value reported for the FTP in the 1980 EPA Gas Mileage Guide. Transportation Lab values for fuel consumption using a direct fuel metering method were approximately 8 to 11% lower than those estimated by ARB using a carbon balance method. The test results for one of the vehicles are shown in Figure 5.

ARB Fuel Testing Driving Cycles

F T P - 75 DRIVING CYCLE



EPA HIGHWAY CYCLE

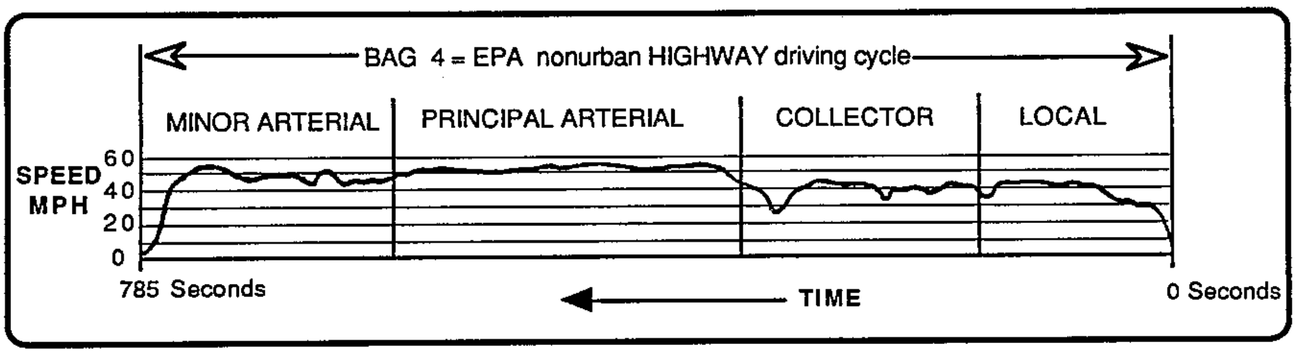


Figure 4

ARB Fuel Meter Calibration : Brown Car

DATE: 11/15/83 TEST: #1	FUEL (ml)			DISTANCE (mi.)			TIME (sec)		MPG		FUEL Factor
	ARB	Tape	Display	ARB	Tape	Display	ARB	Tape	ARB	Tape	
COLD START	711			3.603			507		19.2		
HOT STABLE	728			3.899			867		20.3		
HOT START	607	572		3.604	3.600		507		22.5	23.8	1.058
HIGHWAY	1344	1238		10.313	10.275		770		29.1	31.4	1.079

DATE: 11/16/83 TEST: #2	FUEL (ml)			DISTANCE (mi.)			TIME (sec)		MPG		FUEL Factor
	ARB	Tape	Display	ARB	Tape	Display	ARB	Tape	ARB	Tape	
COLD START	703			3.606			506		19.4		
HOT STABLE	713			3.896			867		20.7		
HOT START	607	568		3.609	3.610		506		22.5	24.1	1.071
HIGHWAY	1350	1253		10.318			770		28.9		

DATE: 11/17/83 TEST: #3	FUEL (ml)			DISTANCE (mi.)			TIME (sec)		MPG		FUEL Factor
	ARB	Tape	Display	ARB	Tape	Display	ARB	Tape	ARB	Tape	
COLD START	707			3.621			506		19.4		
HOT STABLE	716			3.896			867		20.6		
HOT START	598	564		3.621	3.624		506		22.9	24.3	1.061
HIGHWAY	1383	1264		10.31	10.29		770		28.2	30.8	1.092

DATE: 3/12/85 TEST: #1	FUEL (ml)			DISTANCE (mi.)			TIME (sec)		MPG		FUEL Factor
	ARB	Tape	Display	ARB	Tape	Display	ARB	Tape	ARB	Tape	
COLD START	610		584	3.576		3.633	506		22.2		
HOT STABLE	658		624	3.857			867		22.2		
HOT START	530		499	3.576		3.611	507		25.5		
HIGHWAY	1177	1070	1065	10.18	10.21	10.21	771	771	32.7	36.1	1.104

DATE: 3/13/85 TEST: #2	FUEL (ml)			DISTANCE (mi.)			TIME (sec)		MPG		FUEL Factor
	ARB	Tape	Display	ARB	Tape	Display	ARB	Tape	ARB	Tape	
COLD START	657	601	601	3.590	3.615	3.606	510	509	22.4	23.0	1.026
HOT STABLE	700	628	631	4.002	3.866	3.888	867	855	21.6	23.0	1.065
HOT START	536	508	506	3.565	3.592	3.595	506	509	25.2	26.8	1.063
HIGHWAY	1177	1082	1078	10.166	10.185	10.185	770	776	32.7	35.6	1.089

DATE: 3/14/85 TEST: #3	FUEL (ml)			DISTANCE (mi.)			TIME (sec)		MPG		FUEL Factor
	ARB	Tape	Display	ARB	Tape	Display	ARB	Tape	ARB	Tape	
COLD START	625	462		3.611	7.520	7.542	509	509	21.9	26.0	1.187
HOT STABLE	721	635	635	3.992			867	858	21.0		
HOT START	547	513	513	3.566	3.598	3.602	507	509	24.7	26.5	1.073
HIGHWAY	1223	1103	1103	10.214	10.237	10.239	770	769	31.6	35.1	1.111

ARB - refers to the California Air Resources Board (carbon balance based) instrumentation.
Tape - refers to the data gathered on our digital tape recorder.
Display - refers to the values recorded directly off our instrumentation display by the operator.

Figure 5

The differences between our instrumentation and the ARB tests were not entirely unexpected. The EPA, which developed the test method used by the ARB, has published numerous reports indicating poor correlation between these tests and road fuel economy (11) (12).

Two additional tests were run to evaluate fuel meter accuracy. In the first test, a measured volume of fuel was run through the Fluidyne meters and the meter output was compared to the amount of fuel input. This test was run both while the vehicle was operating and through the meter directly with the vehicle not operating (bypassing the fuel pump and delivery lines).

The repeatability of the test with the research vehicle not running was less than 1%, whereas with the car running it was approximately 3.5%. For both test conditions, each meter recorded a value approximately 2% lower than the statically measured volume.

The second type of test performed on the Fluidyne meters is described below.

FUEL FLOW CALIBRATION PROCEDURE

1. Obtain a sufficient quantity of pump unleaded gasoline in a suitable container
2. Fill the calibration reservoir to top of sight level tube.
3. Install reservoir in vehicle and purge air from the fuel lines.
4. Bleed air from the air accumulator.
5. Remove reservoir from vehicle and refill reservoir just prior to test.
6. Immediately weigh reservoir and fuel, and note temperature of fuel. Record weight to nearest 0.1 gm and temperature to nearest 0.2 degree C.
7. Connect remote solenoid switch.
8. Start vehicle on vehicle fuel tank then switch to calibration reservoir. At the same time start the fuel flow meter and record flow on tape.

9. Take simultaneous readings of the reservoir weight, fuel temperature, and fuel meter reading at various points as the vehicle is running.

10. At the conclusion of test, switch back to vehicle fuel tank and, at the same time, stop the recorder. After this, stop the engine and immediately weigh and record the weight and temperature of the remaining fuel.

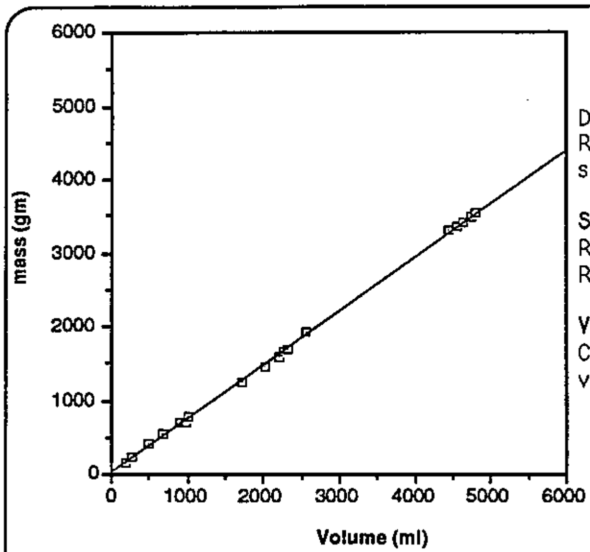
11. Repeat test for duplicate results.

12. Upon conclusion, an adequate sample of gasoline was taken from the container to our chemical laboratory for a specific gravity test.

The above method was considered the most accurate and valid of the calibration procedures. It accurately duplicates real-world operating conditions by allowing for possible inaccuracies with the flow meter as the fuel surges and ebbs in the fuel bowl. The results of these tests are given in Figure 6.

In addition to the laboratory testing previously described where a measured volume of fuel was metered, two "road" tests were conducted. These tests were made while the research vehicles were driven from the El Monte Laboratory to TransLab in Sacramento (approximately 450 miles). The vehicles' gas tanks were topped off in El Monte and driven back to Sacramento where the fuel tanks were again topped off. Both meters again underestimated the fuel consumed as compared to the amount required to refill the gas tank. The meter readings were low by 2.5% and 4.2%, although both vehicles recorded a fuel consumption rate of ~32 MPG for the trip.

Brown Citation Mass:Volume Fuelmeter Calibration



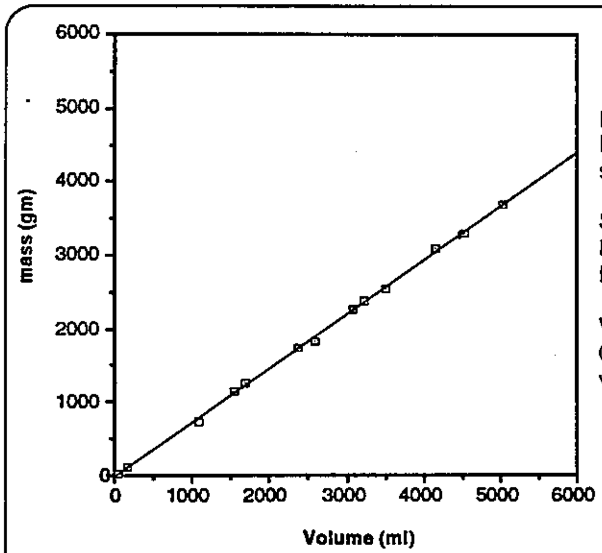
Dependent variable is: mass
R^2 = 99.9% R^2(adjusted) = 99.9%
s = 30.66 with 18 - 2 = 16 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	25387343	1	3e+7	27014
Residual	15036.3	16	939.770	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	17.2260	12.41	1.39
volume	0.730550	0.0044	164

The slope of the line indcates a density of 0.731 gm/ml. The measured density of this fuel at 25°C is 0.721 gm/ml. Therefore, the real fuel calibration factor is **0.986**

Silver Citation Mass:Volume Fuelmeter Calibration



Dependent variable is: mass
R^2 = 99.9% R^2(adjusted) = 99.9%
s = 33.51 with 14 - 2 = 12 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	18286405	1	2e+7	16286
Residual	13473.6	12	1122.80	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	-14.7206	17.87	-0.824
volume	0.736018	0.0058	128

The slope of the line indcates a density of 0.736 gm/ml. The measured density of this fuel at 25°C is 0.721 gm/ml. Therefore, the real fuel calibration factor is **0.980**

Figure 6

2.3 SPEED AND DISTANCE

We used a Numetric model DE-1073 for distance measurement. This distance measuring instrument (DMI) has a transmission speedometer cable transducer that outputs 6 electric pulses per revolution. This yields a resolution of about 1 foot. These pulses go to a dash-mounted accumulator that displays the cumulative feet traveled.

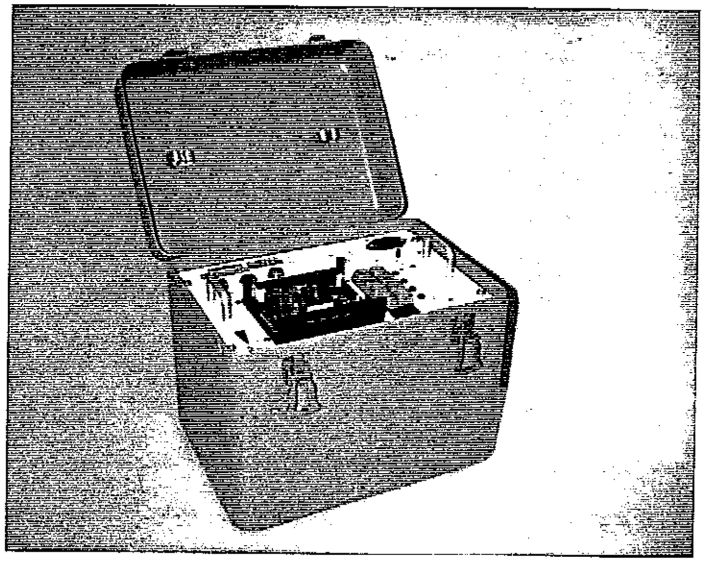
2.3.1 CALIBRATION

These units were calibrated on a one-mile test section of straight flat roadway before every data collection session. The DMI calibration factor was adjusted to yield exactly 5,280 feet for this test section. With a stated accuracy of 2 feet per mile, these meters routinely yield distances which varied only ±25 feet on a 7-mile run of curved road with numerous speed changes during actual data collection. Most of this variation was thought to be due to operator error in hitting the sync mark while driving in heavy traffic.

2.4 DATA RECORDING

Fuel and distance data were recorded on a Memodyne Microtran Data Logger 2 (Figure 7) with event clipboard. This device takes the calibrated output from the distance measuring instrument and fuel totalizer once a second, digitizes this information and spools it to a tape drive. The 7-event keypad/clipboard produced a 3-bit BCD signal and also sent it to the data logger. Figure 8 gives a schematic of the entire data collection system.

The data logger recorded all this information on a single-channel digital tape drive once per second. Since this tape drive only had the capability of recording 1 byte per write, all the information had to be encoded into the range 0-255 (hex 0-FF). These data were not recorded in normal ASCII format. It was done by recording all distances, in units of feet per second, in the binary range 0-127. Fuel, in units of 0.1 ml/sec, was recorded as values between 128 and 191, (i.e. a byte of 140 would be 140-128 = 1.2 ml of fuel per second). Events had the value of 192 added to them and were recorded between the range of 193 and 199 (i.e. 195 = event #3). Additionally, every time an event button was pushed, the data logger would record the time, fuel, and distance traveled since the last fuel-distance pair was written the previous second. This allowed the exact time, distance, and fuel consumption to be determined at the instant any event was recorded. Other byte codes had other meanings.



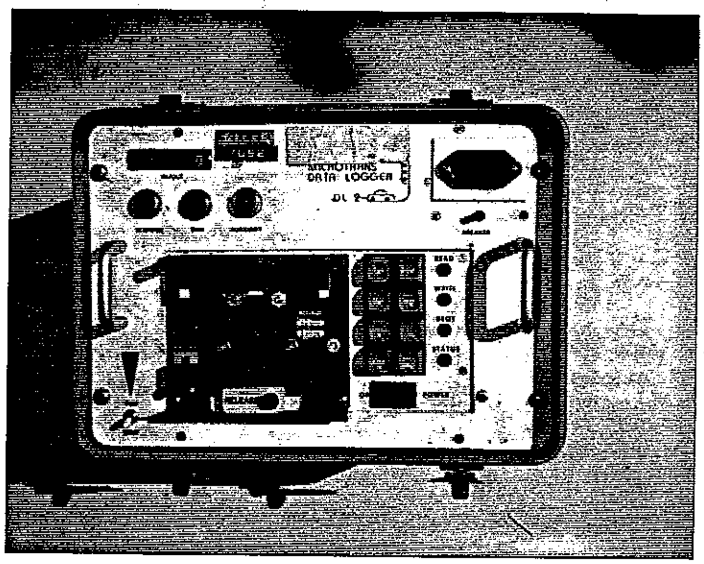


Figure 7, DL-2 DATA LOGGER.

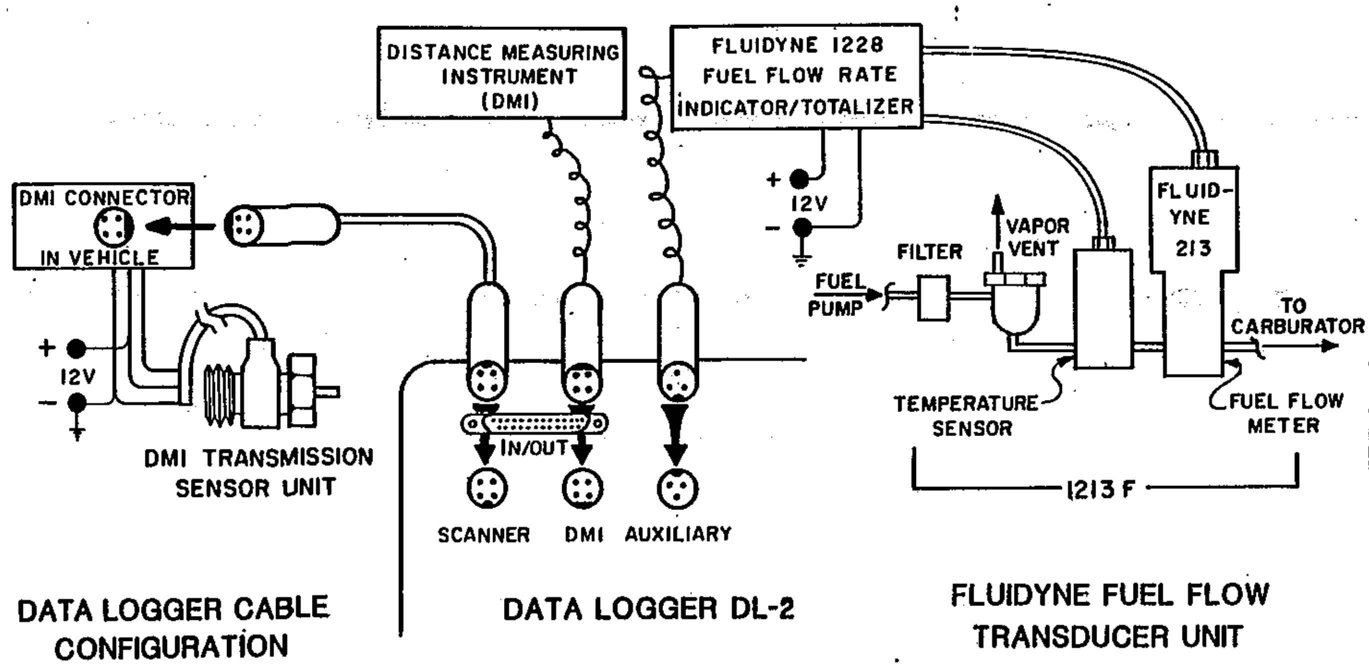


Figure 8
Data Logging Instrumentation Schematic

This recording format was quite unique. Although it could record all the pertinent information, it did require a rather elaborate interpretation scheme to break distance, fuel, and events out of the spooled tape stream. This system worked relatively well when we inherited it in 1981, however, over the years the system degraded substantially. Often inadvertent information would be inserted into the tape stream, or more often, some data would be left out. Immediately before starting this project, we found that when a distance of 10 feet was sent to the Memodyne, it recorded it as 0.

This required us to set up a rather elaborate set of error checking algorithms to resurrect lost or inappropriately recorded data.

Fortunately, all the data recorded by the Memodyne could be summarized and checked against the totals manually recorded by the fuel and distance totalizers. In almost all cases, the corrected data were within 0.5% of manually recorded data.

3. SITE SELECTION

3.1 CONSTRAINTS

The ideal site for studying freeway congestion would be one with 1) high traffic volume for both main line and ramps, with enough variability to give a good cross section of different levels of service, 2) pockets of concentrated congestion where stop-and-go conditions are induced by the high traffic volume, and 3) minimal grades so that changes in fuel consumption would be more strongly influenced by congestion rather than change the gravitational potential. Of equal or greater importance is having the site be equipped with a high density of main line and ramp vehicle detectors so that traffic volumes can be accurately determined. Ideally, both the high traffic volume and detectors should be bidirectional so that data can be gathered in both directions simultaneously.

Finally, the site should be at least 5-miles long so that a continuous section of freeway can be analyzed for changing conditions with a minimum of boundary condition effects.

3.2 POTENTIAL URBAN SITES

As simple as the above selection criteria sound, they greatly restrict the list of potential sites. In California in 1985, the year the data were collected, the only sites that experienced a significant degree of congestion were in the four major metropolitan areas: Sacramento, San Francisco (Bay Area), San Diego, and Los Angeles.

Sacramento, although occasionally experiencing significant traffic delays, could not be expected to consistently produce reliable congestion. The San Francisco Bay Area did have significant congestion in a number of areas. However, the only area that had a high density of main line traffic loop detectors (San Jose) did not have communication between the traffic counters, and would have necessitated installing recorders at every controller.

It was found that the only areas that had continuous sections of main line traffic detectors were those areas that used ramp metering. Ramp metering, after all, provides the economic justification for the expense of installing and maintaining these detectors. Unfortunately, this also means that there is a significant degree of control over the traffic which reduces the amount of true unconstrained congestion. This was a factor for all sites.

Both Los Angeles and San Diego had areas where there were high traffic volume freeways that had existing main line detectors. One site was found in each area that was suitable for data collection.

3.3 SELECTED SITES

In Los Angeles, a site was identified on Route 101 between post miles 1 and 8. This route is known as the Hollywood Freeway and has a national reputation for being one of the most heavily congested pieces of pavement in the world (13). It runs between Hollywood and downtown Los Angeles and catches commuter traffic in both directions day and night. It was one of the first freeways to institute ramp metering in the early 1960's and still has many of the original detectors and equipment. The plan and profile views of the northbound and southbound runs are given in Figures 9-12.

In San Diego, a section of Interstate 8 between El Cajon and downtown San Diego was found to contain the essential site traits that we were looking for. Although this section of freeway did not have bidirectional congestion, it did show a significant reduction in level of service in the peak direction. Access and egress to the study area was very good, thereby reducing the turnaround time between runs. This site did have more significant grades then would have been ideal. However, due to the nature of the topography of the San Diego area, it is virtually impossible to find a flat area of any significant length.

Overall, the traffic monitoring system in San Diego was the best that we found. Although due to construction of the I-15 interchange during the period of our data collection, the I-15 to I-8 ramps were not functioning. This required the use of two mechanical hose counters for these ramps.

The AM (westbound) site began in El Cajon at the 2nd Street on-ramp (P.M. 17.2) and covered approximately 5-1/2 miles to the Jackson Road off-ramp. This section of I-8 serves also as Rte 67 for most of the study area. Rte 67 enters at approximately P.M. 16 and exits at approximately P.M. 13. A significant portion of the congestion along this section of I-8 is due to Rte 67 traffic. A major downhill grade starts at P.M. 13 and extends through the end of our data collection site. This downhill grade was not considered important because in most cases the significant freeway congestion was relieved by the Rte 67 off-ramp just before the grade started and very little useful heavy congestion data were collected at the grade.

LA 101 (Hollywood Freeway) Northbound Plan View

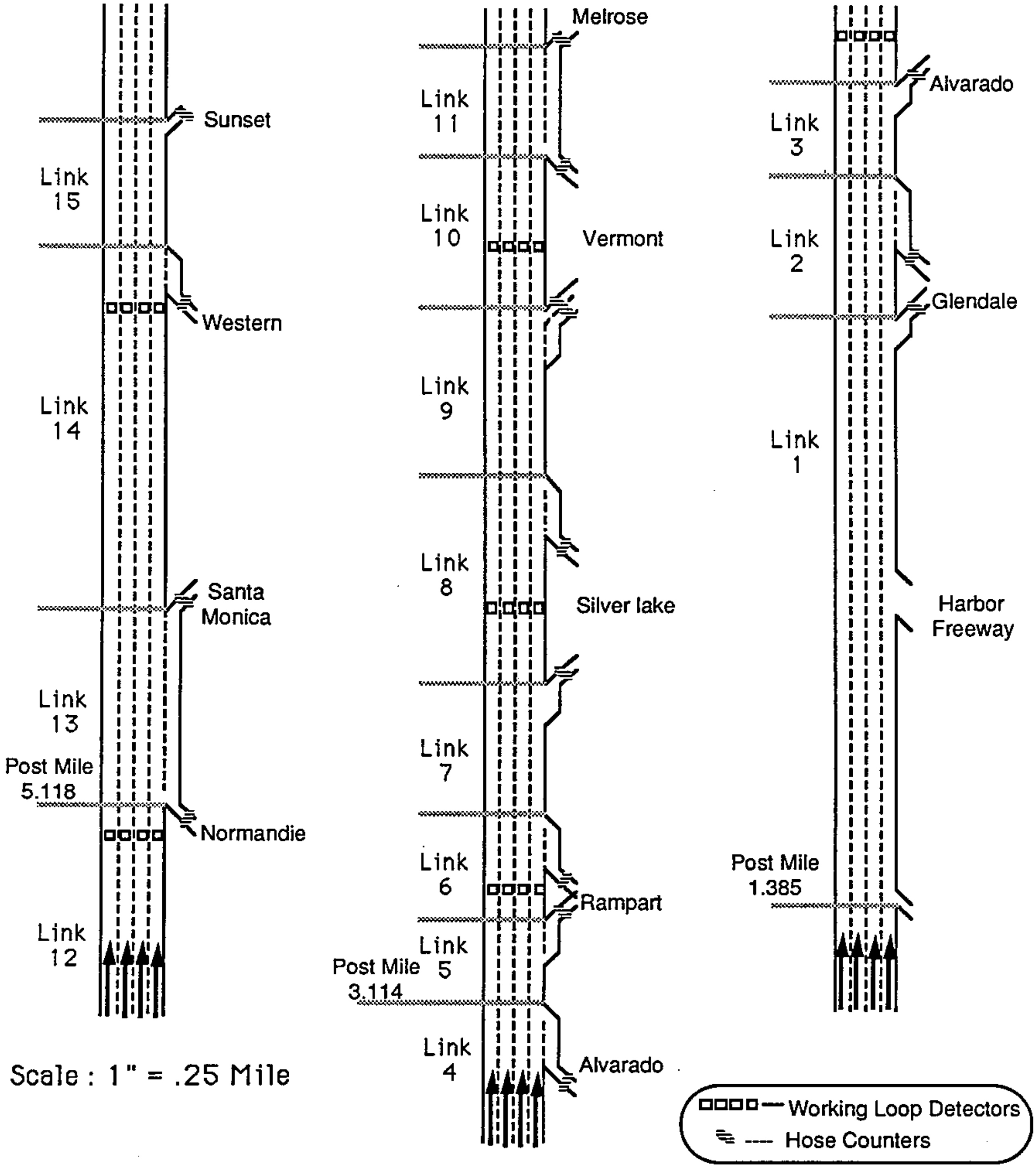


Figure 9

LA 101 (Hollywood Freeway) Southbound Plan View

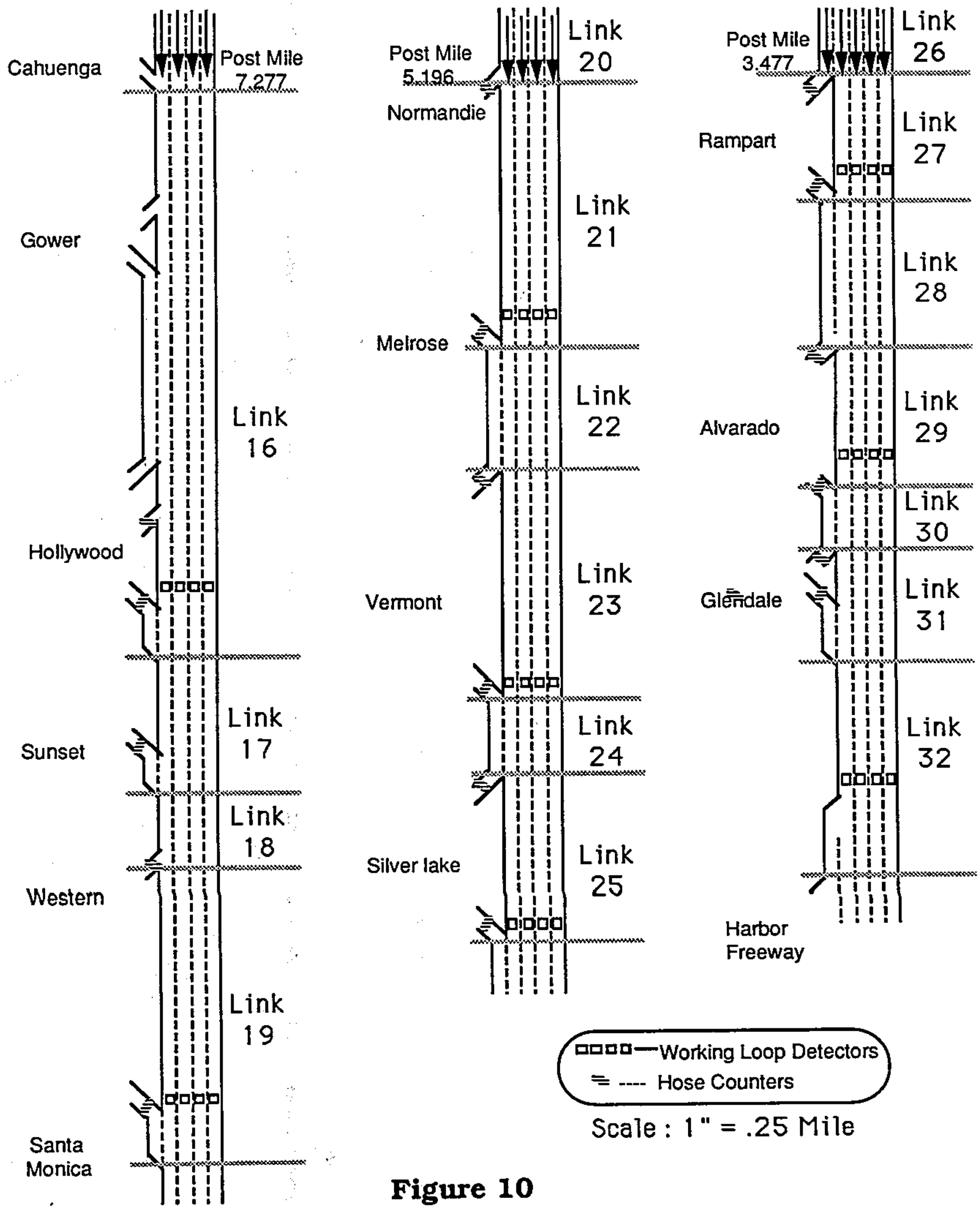


Figure 10

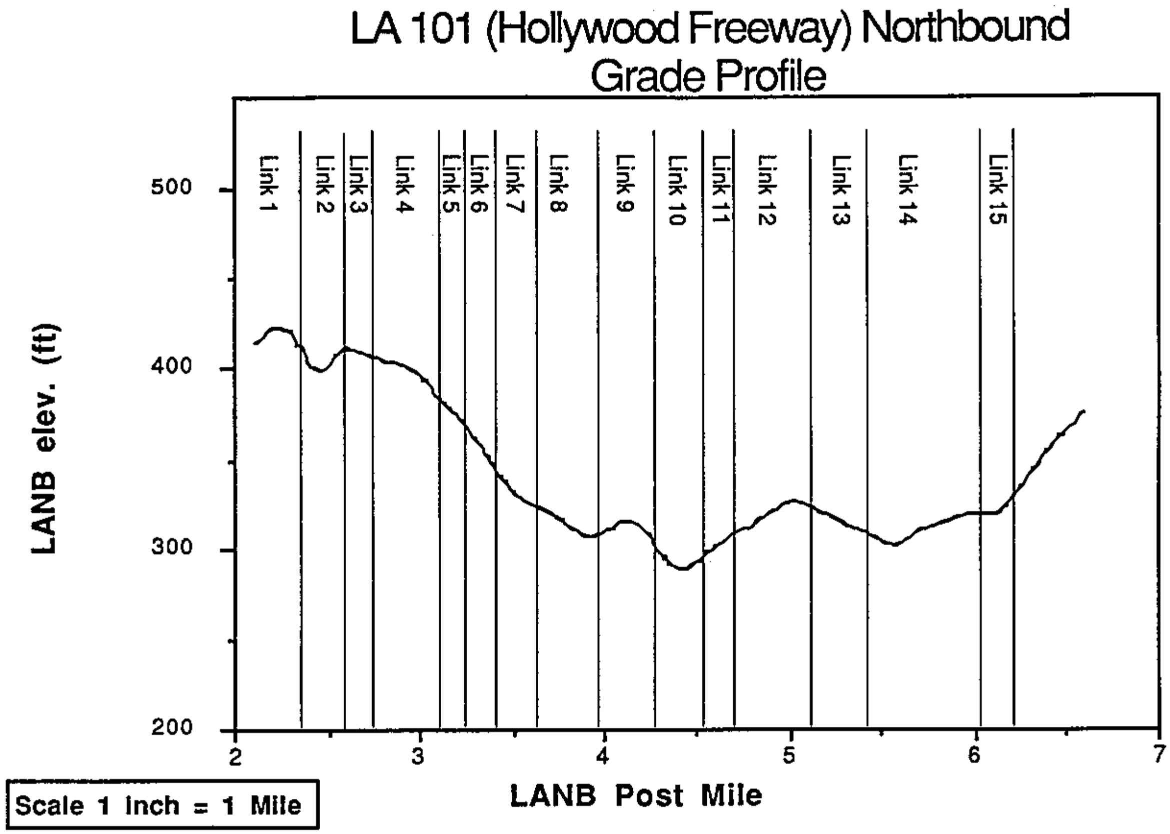


Figure 11

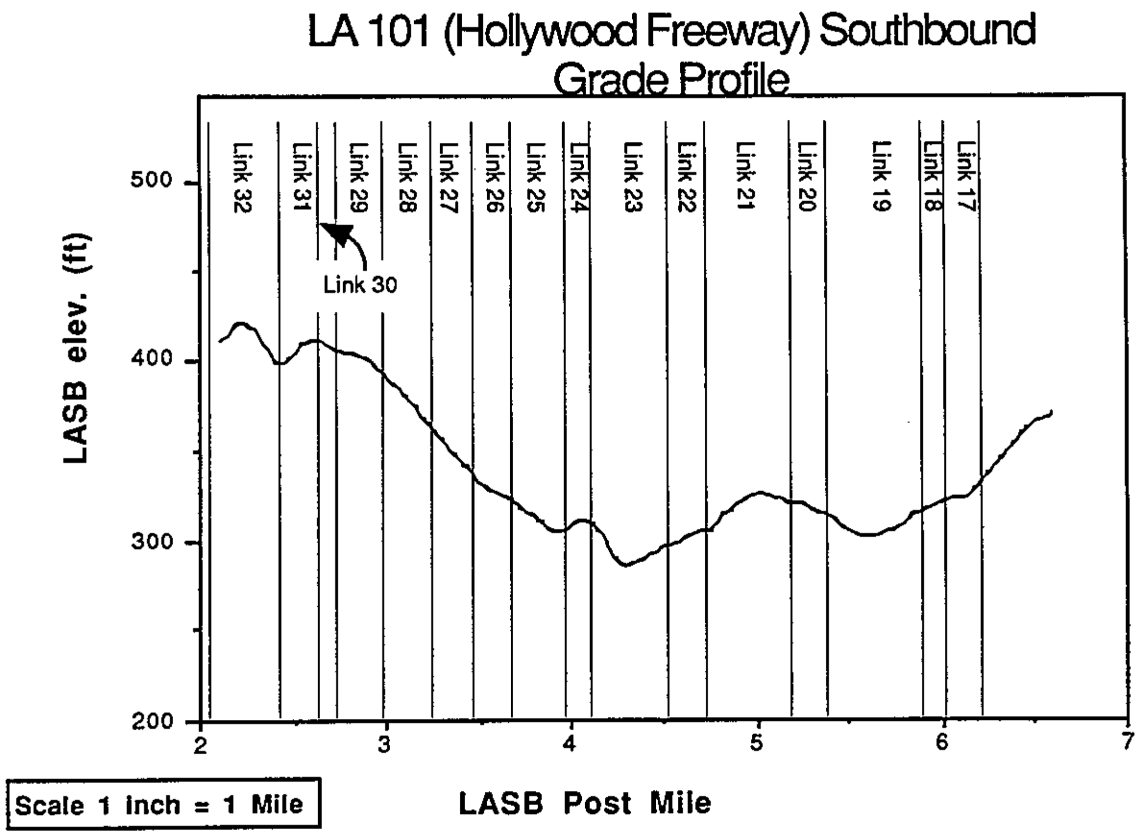


Figure 12

The PM (eastbound) site began downtown at the Mission Center on-ramp (P.M. 3.2) and covered a little more than six miles to the College Avenue off-ramp (P.M. 9.4). This stretch of I-8 crosses the paths of three major freeways: Rte-163, I-805 and I-15. These connected freeways provided large amounts of on-off-ramp traffic. A 1-1/2 mile ~ +3% grade was present at the end of the data collection run which always experienced congestion due to the on-off-ramp activity at College Avenue (site of San Diego State University). The plan and profile views of these sites are shown in Figures 13-16.*

The major differences between the Los Angeles and San Diego sites are their age and features. Rt 101 was constructed in the 1940's and was modified in the 1950's. Since that time no major changes to the original profile and alignment have occurred. The design procedures in use during this period allowed much tighter horizontal and vertical curves and narrower lanes and median/shoulders than are allowed today. By contrast, the I-8 roadway was constructed with wider right of way allowing numerous lanes, longer sight distances, longer merging lanes and larger tangent sections.

For both sites, horizontal and vertical alignment data were collected from the latest as-built plans. This information was reformatted by computer and input into the VEHC fuel prediction model. Additionally, this information was used to generate plan view segments of the roadway for correlation with speed, volume, and fuel consumption on the contour plots (described later).

* There are two grade profiles shown for SD 8 Eastbound on Figure 16. The darker line is the actual grade. The shaded line represents the grades the VEHC fuel consumption was based on (1000 feet was mistakenly left out of the VEHC grade profile). VEHC fuel consumption values based on these incorrect grades (for links 51 - 56) are invalid and were excluded from any further analysis.

SD 8 Westbound
Plan View

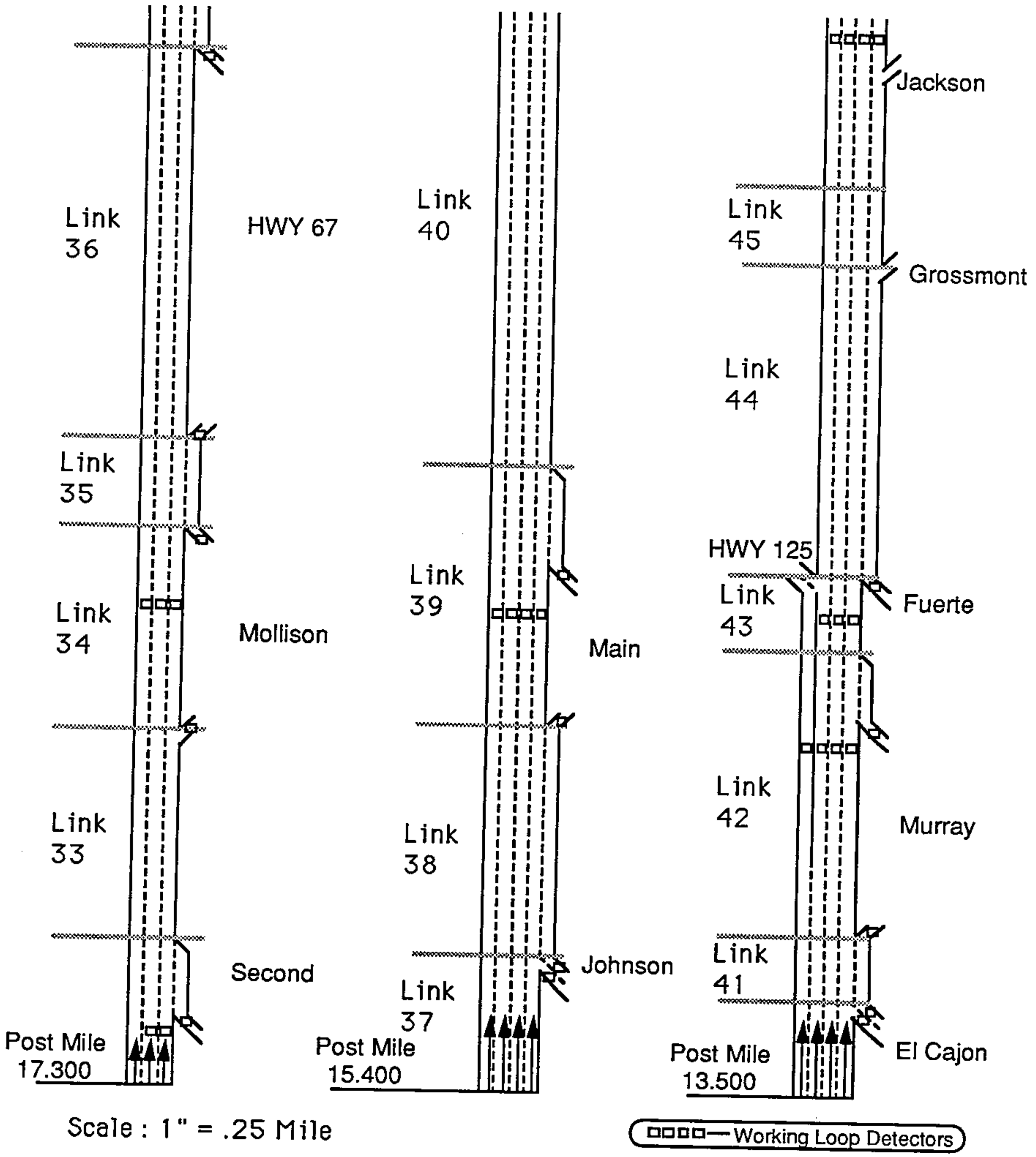


Figure 13

SD 8 Eastbound
Plan View

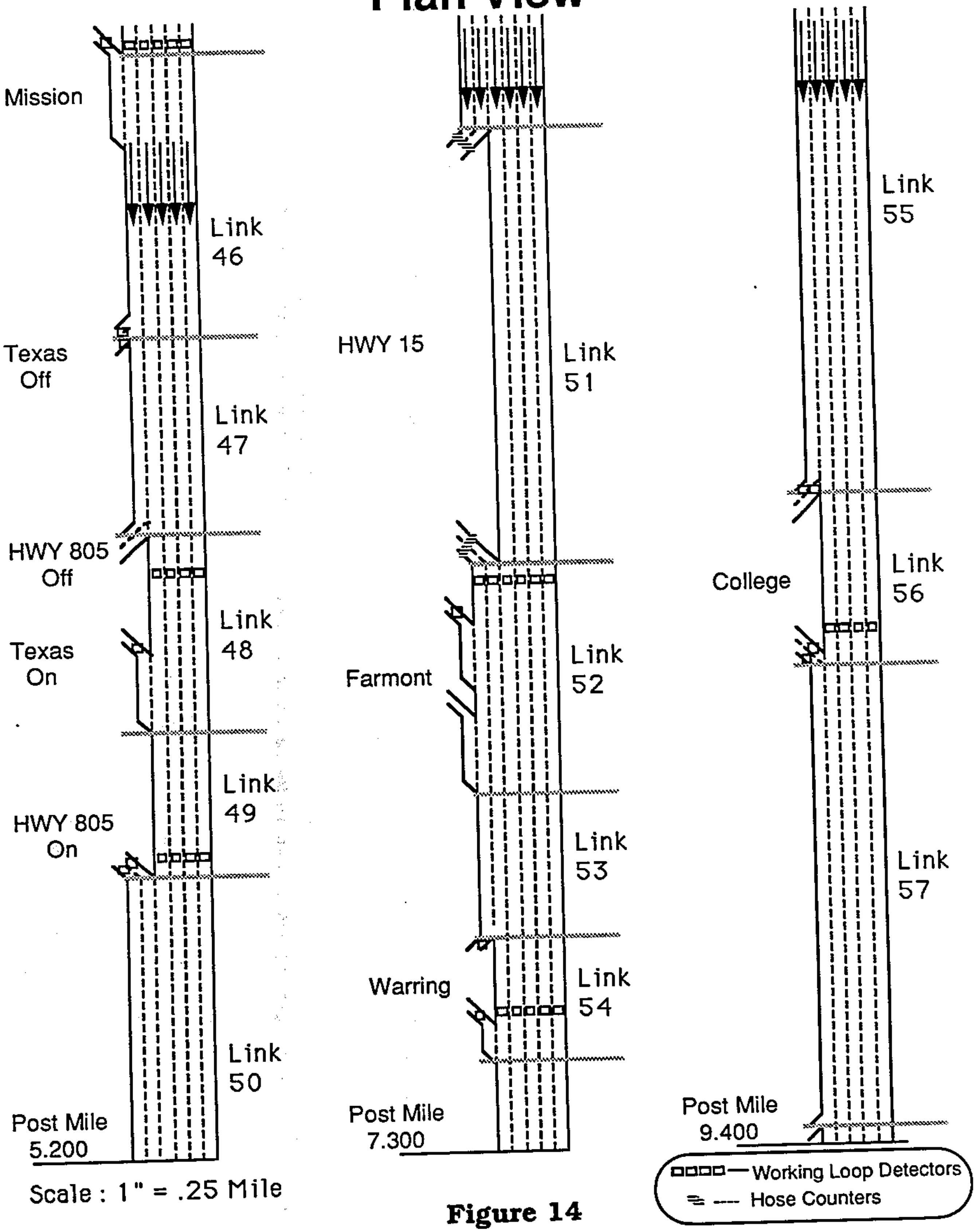


Figure 14

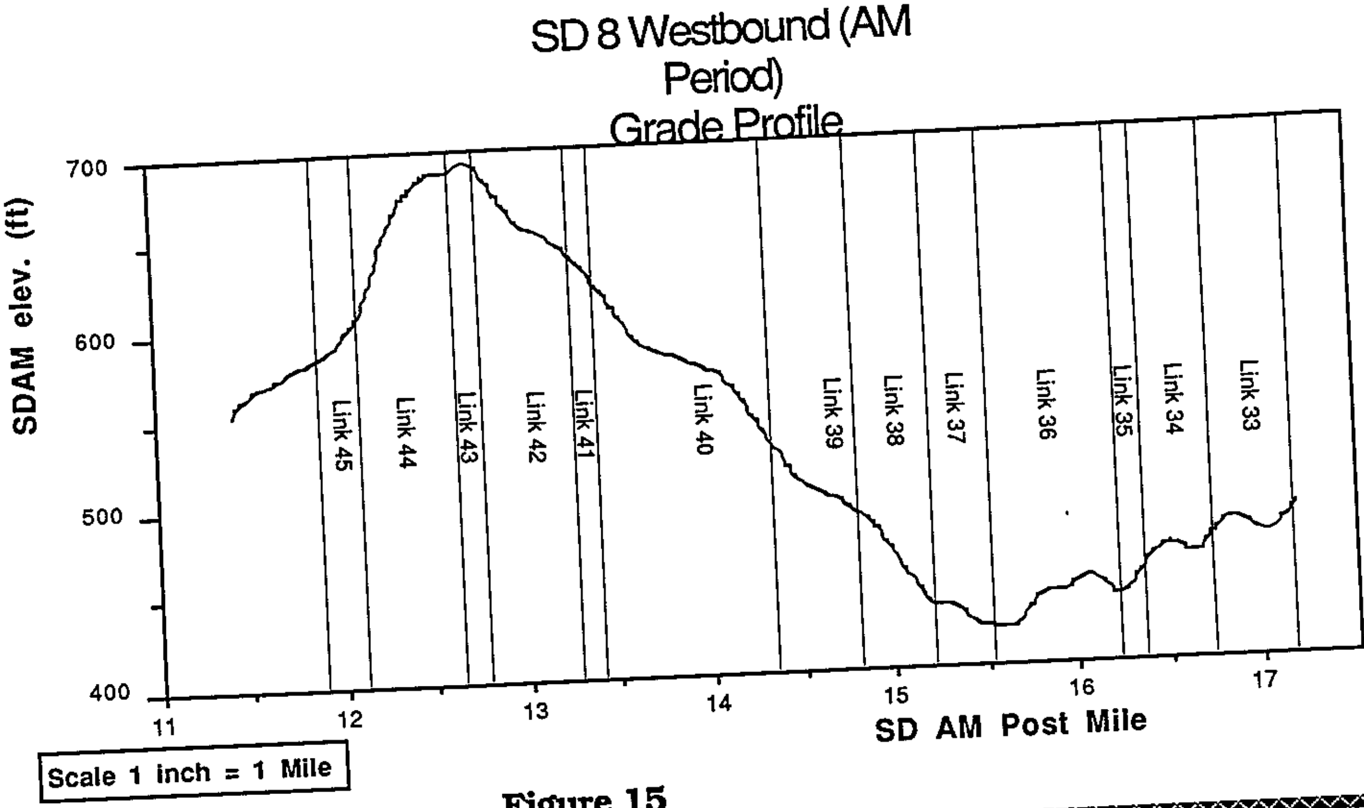


Figure 15

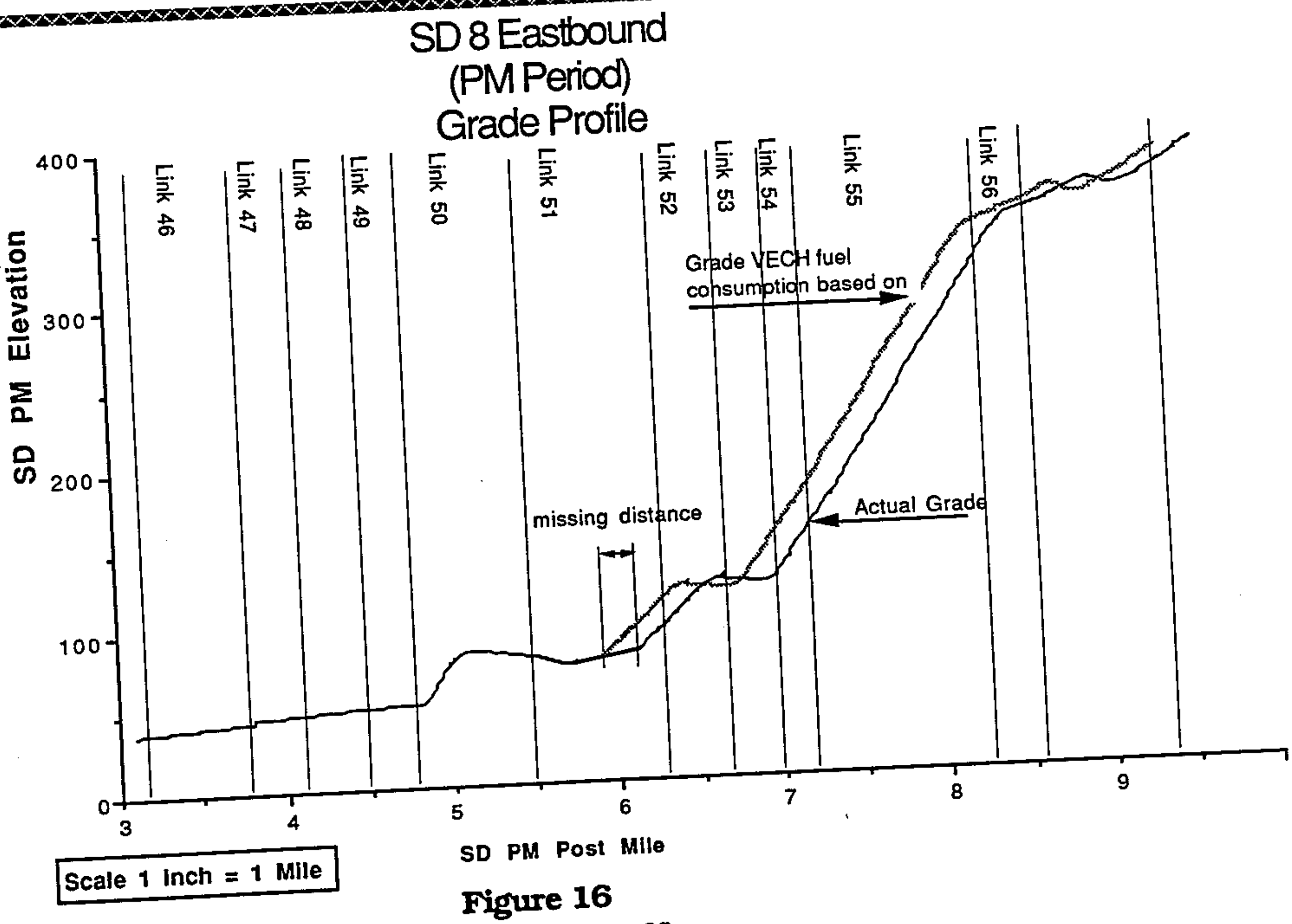


Figure 16

4. DATA COLLECTION

All data were collected on consecutive weekdays for each location. Past studies have shown that variations due to external influences (school, vacation, holidays, etc.) can introduce considerable inconsistencies in driving patterns (14). Eleven consecutive weekdays of data were collected in San Diego and 10 consecutive weekdays were collected in Los Angeles.

4.1 TRAFFIC VOLUME

For Los Angeles, main line traffic volumes were collected by loop detectors located between most ramps. Data were collected in both directions for the entire study period between 6 and 9 AM and between 3 and 6 PM. Each set of detectors was controlled by a 170 controller that also controlled the timing sequence for the ramp-metering light that influenced on-ramp vehicle volumes. These controllers would total each lane's volume and occupancy and report it back to the District HQ every 30 seconds by modem.

Ramp volumes in Los Angeles were gathered by Leopold Stevens pneumatic hose counters. These are battery-powered, mechanical devices that wrote the ramp volume to paper tape once every 5 minutes. These counters were installed and maintained by maintenance crews at our request. They recorded the ramp volumes for the entire 2-week period. These pneumatic counters were considered less accurate and reliable than the loop detectors (15). The maintenance crew indicated we should expect ±10% accuracy at best. Potential causes of inaccuracy were due to air leaks, loose traffic detector hose, mechanical malfunction, low batteries, and faulty or corroded connections.

The Los Angeles main line detector system used for this study was one of the oldest in the world. Due for an upgrade shortly after our data collection was completed, it had aged detectors, old wiring, faulty pavement slabs, and overloaded communication lines. The net effect was that detectors would randomly go out for a few hours to a few weeks. Some detectors were nonoperational for the entire study period. This put a lot of holes in the traffic volume data base.

This main line traffic detector system was being modified by a contractor during the time of our data collection. The State only had use of it for a few hours a day, so the system was in a constant state of upheaval. This was not discovered until after the study had started.

Both the main line and hose detectors for Los Angeles had data dropouts from one minute to two days duration. Although an attempt was made to synchronize all traffic detectors, each of the hose counters has an independent clock and some were found to be off by 2 to 3 minutes.

All of the traffic data for San Diego were gathered by loop detectors that fed into 170 controllers communicating directly with the District H.Q. computers, with one exception. Due to ongoing construction, Route 15 loop detectors were nonfunctional and it was necessary to use hose counters for those ramps.

The percentage of busses and trucks was estimated at 7 percent for both sites.

4.2 SPEED AND FUEL DATA

Speed data could have been generated through the main line loop-detector system alone. It is calculated from the average residence time each vehicle spends over a loop. This method must assume an average length of vehicle. It is not considered accurate for a number of reasons. We used our vehicle mounted distance measuring instruments for all speed data.

A typical vehicle data collection procedure would be as follows. Before every run, the vehicle would be thoroughly warmed up, tire pressure standardized, gasoline tank filled (to assure consistent weight), and ambient temperature recorded if it deviated significantly from the norm. At the beginning of each run, the start time would be recorded by hand. The data logger would be turned on at a predetermined run start marker, usually a highway paddle or gore point. The event keyboard was used to indicate the lane number being traveled in, accidents, and interrun distance syncs. At the end of the run, the data logger and fuel totalizer would be turned off. This also disengaged the DMI totalizer. The run number, direction, approximate run time (from the operator's watch), total fuel and distance would be recorded on the log sheets for each run. Figure 17 shows the data collection instrumentation in the vehicle.

While the data logging was taking place, the fuel and distance data would normally be written to the tape drive once per second while the DMI and fuel totalizer were cumulating distance and fuel independently. This system offered the operator no feedback to indicate that the information was being recorded on tape. This was an occasional problem.

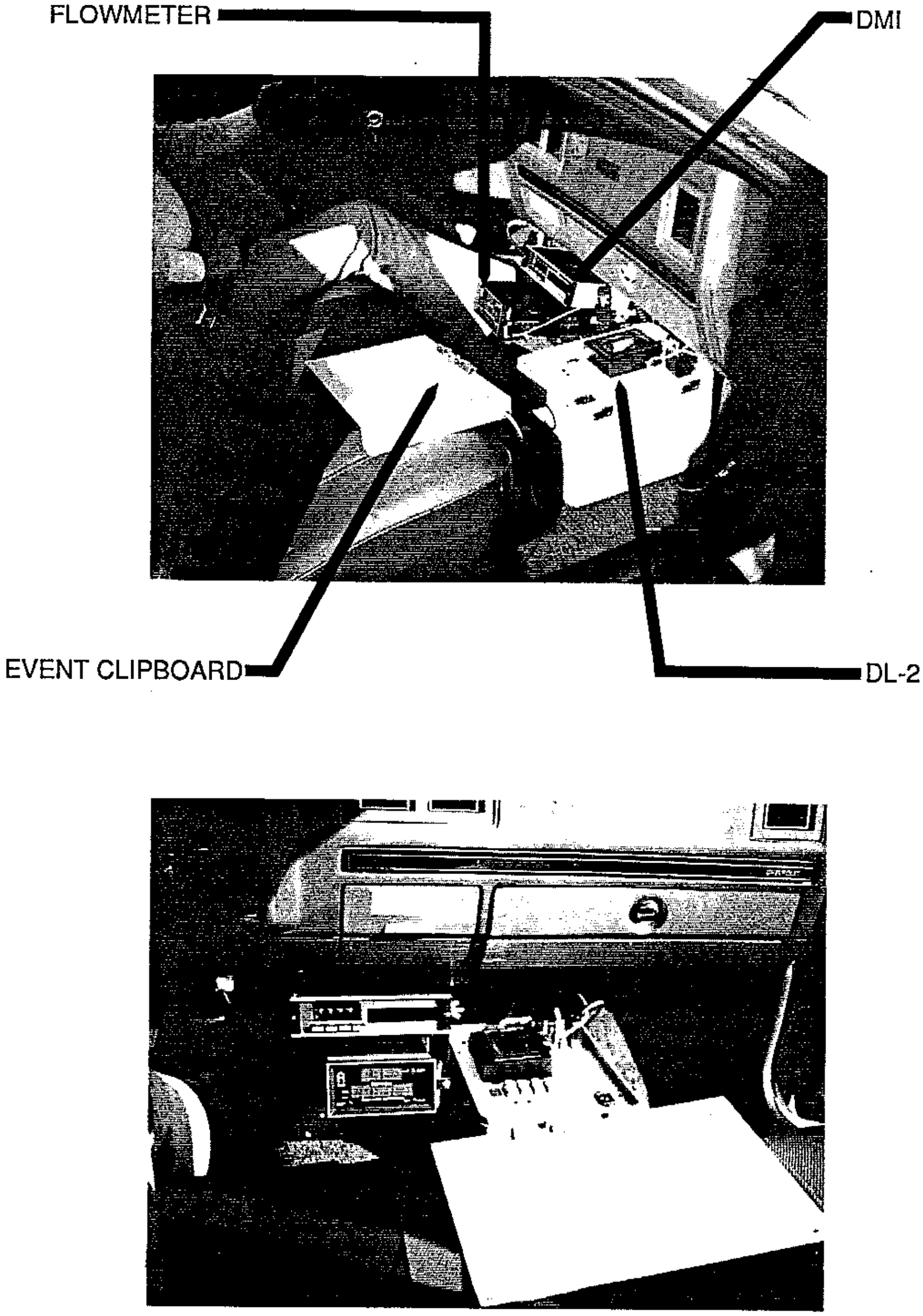


Figure 17, VEHICLE WITH INSTRUMENTS INSTALLED FOR OPERATION.

The driving technique used was to simply stay in one lane throughout the entire run. The driver would maintain the average speed for that lane. The chosen lane would be rotated for each consecutive run, so that all lanes got equal coverage. This technique was considered simpler and less problem ridden than other driving techniques such as the car following method (16). The only exception to this rule was when the driver was behind a slow vehicle such as a bus or truck where the majority of traffic was passing it. In these cases, the driver would also pass the vehicle. These cases were always noted by the lane change event codes recorded by the data logger. Only one driver was used for each vehicle at each site.

4.3 FIELD DATA ANALYSIS

Some simplified analysis of the vehicle speed and fuel data was necessary to assure that the data were being recorded correctly. A desktop microcomputer was brought to the field office and a program was written to read in the tapes and separate the data into flags, fuel, and distance files. Speed vs distance plots with event markers shown were generated in the field on a portable printer. These outputs also displayed the total fuel and run time, so they could be correlated with the field log sheets. Examples of the field plots and log sheets are shown in Figure 18 and 19.

It should be noted that the link boundaries used early in this project (as shown in Figure 19) are not necessarily the same as were adopted in the final analysis. The final link boundaries are indicated in Figures 9 through 16.

DATE: 5/21/05 DAY: Tues PERIOD: PM WTHR: Clear/Hot radio TEMP: 73	beg fuel tank 27.4	ROAD LOG SHEET PROJECT: 637321 FILE 123	PLEASE NOTE THE DISTANCE & FUEL READINGS AT THE END OF EACH RUN	TRANSPORTATION LAB CAR I.D. Silver
DRIVER: Herrington OPERATOR:		CROSSING STREETS		TIRE PRESSURE RF 36 LF 35 RR — LR —

start	Lane #	Hollywood Blvd.	Western Ave.	Normandie Ave.	Vermont Ave.	Rampart Ave.	Alvarado St.	Finish	RUN TOTALS
RUN NO. 1-S START TIME 3:22:00 END TIME 3:36:00	3	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P		Dist 30609 Fuel 587.3
RUN NO. 2-N START TIME 3:32:39 END TIME 3:40:49	3	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P		Dist 31593 Fuel 634.3
RUN NO. 3-S START TIME 3:42:39 END TIME 3:51:05	4	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P		Dist 30604 Fuel 608.4
RUN NO. 4-N START TIME 3:53:32 END TIME 4:02:10	4	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P		Dist 31584 Fuel 619.9
RUN NO. 5-S START TIME 4:02:15 END TIME 4:09:54	1	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P		Dist 30596 Fuel 607.6
RUN NO. 6-N START TIME 4:14:49 END TIME 4:22:57	1	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P	L R 1 2 3 4 5 P		Dist 31575 Fuel 736.6

Figure 18

Field Tachograph Plot

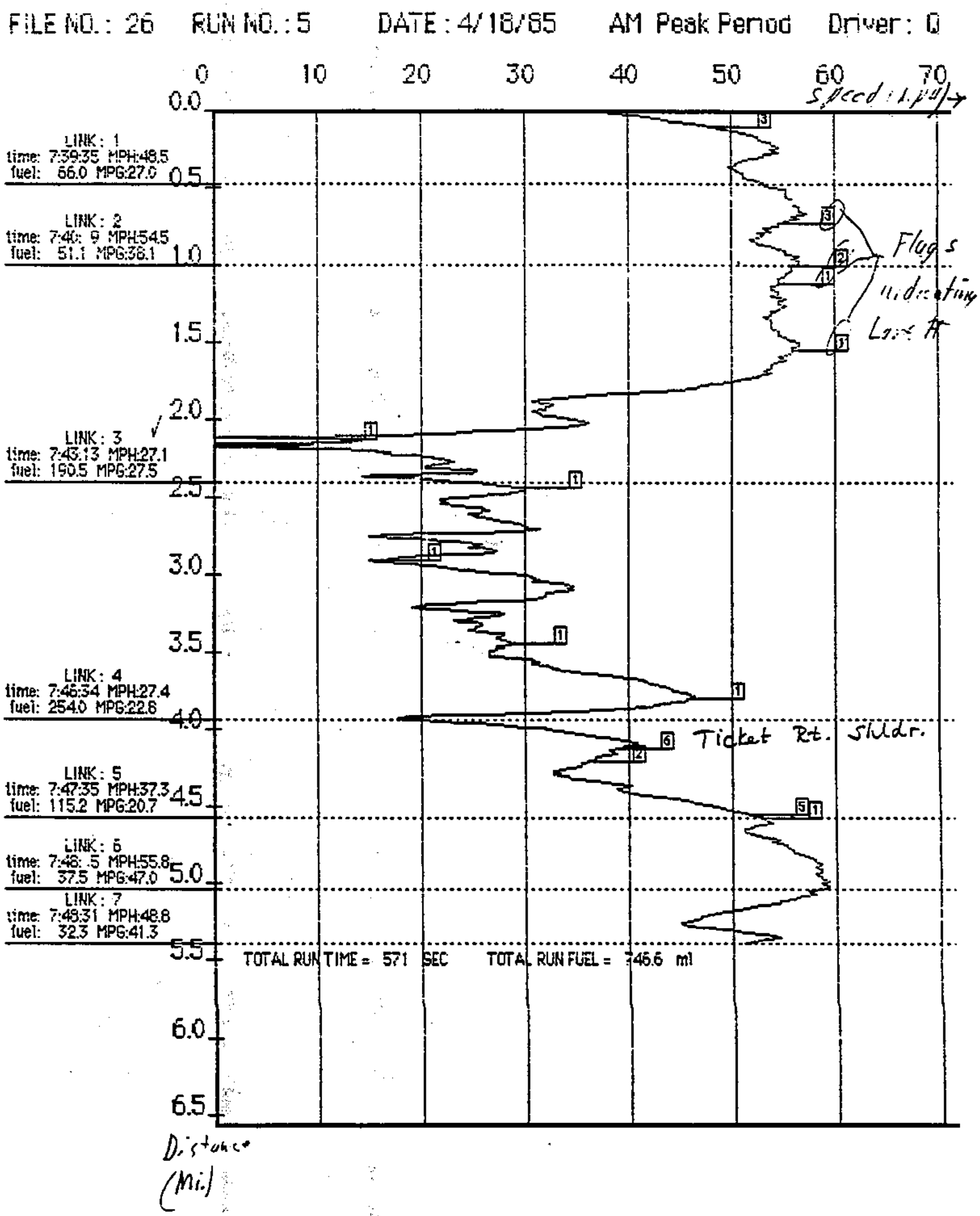


Figure 19

5. OFFICE DATA ANALYSIS

5.1 TRAFFIC DATA

All data collection sites were selected to assure a continuous section of roadway traffic sensors. This allowed calculating the actual main line or ramp data at any time.

The collection of this traffic volume data was a relatively routine task for the districts. These data were gathered and stored on their own "Modcomp" computer system. Unfortunately, we learned after the study had started that the traffic volume information had rarely, if ever, been transferred to another computer system for further analysis. A whole new set of file formatting, error checking, and transfer utilities had to be developed. This was by far the most difficult and time-consuming aspect of the project.

The actual transfer of data from the district's traffic computers to our mainframe was accomplished by generating a report format on the district computer and writing it to magnetic tape rather than hardcopy output. We then had to strip the headers, error messages, line feeds, etc., to extract the useful data.

Figure 20 shows a typical hard copy print of a Modcomp output. There were various data dropouts in the system where the base traffic data had to be regenerated.

5.1.1 MISSING VOLUME DATA GENERATION

Both the Los Angles and San Diego sites were selected so that any main line link that didn't have a detector could have its volume calculated from adjacent main line and ramp detectors. In a few cases there was redundancy, allowing us to calculate main line volumes from two directions - and thereby check the accuracy of the measurements.

The generation of data where there were no direct measurements was broken down into two parts. First, we attempted to regenerate the original detector information on the numerous occasions where the detector was "down". Second, we calculated the main line and ramp volumes without detectors from the working detectors.

Typical Modcomp (Traffic Volume Counter) Output

CALTRANS AUTOMATED TRAFFIC MANAGEMENT AND INFORMATION SYSTEM (CATMIS) DISTRICT 7 - TRAFFIC OPERATIONS CENTER PAGE 4

1 MINUTE OCCUPANCY AND VOLUME REPORT FROM 05/15/85 AT 1501 TO 05/15/85 AT 1800 MLD 1
170 CONTROLLER FOR L.101.N, 4.5 AT VERMONT

TIME	MAIN LANE #1 OCC	VOL	MAIN LANE #2 OCC	VOL	MAIN LANE #3 OCC	VOL	MAIN LANE #4 OCC	VOL	LANE #5 OCC	VOL	LANE #6 OCC	VOL	LOCATION AVERAGES OCC	VOL	5MIN VOLUME TOTALS	15 MIN VOLUME TOTALS	60 MIN VOLUME TOTALS	ESTMD SPEED (2.38)
1716	46.11	19	48.83	20	41.33	21	39.89	25	0.00	0	0.00	0	44.04	85				12.14
1717	33.83	19	43.56	21	30.61	19	21.56	20	0.00	0	0.00	0	32.39	79				15.35
1718	12.67	15	14.56	16	15.44	17	14.11	18	0.00	0	0.00	0	14.19	66				29.25
1719	21.39	22	12.11	15	14.06	15	26.67	23	0.00	0	0.00	0	18.56	75	361			25.43
1720	12.67	13	16.67	19	9.89	12	11.11	12	0.00	0	0.00	0	12.58	56				28.00
1721	6.11	9	11.17	11	9.72	8	7.00	9	0.00	0	0.00	0	8.50	37				27.39
1722	7.22	12	4.44	7	3.61	7	7.50	12	0.00	0	0.00	0	5.69	38				41.97
1723	15.72	22	14.28	22	16.22	23	15.17	21	0.00	0	0.00	0	15.35	88				36.08
1724	17.17	21	21.17	22	18.33	22	17.50	23	0.00	0	0.00	0	18.54	88	342			29.86
1725	20.72	23	20.89	24	17.83	23	15.83	21	0.00	0	0.00	0	18.82	91				30.42
1726	31.33	10	23.94	20	23.17	23	21.06	22	0.00	0	0.00	0	24.87	83				20.97
1727	35.33	14	53.94	15	40.11	18	48.94	18	0.00	0	0.00	0	44.58	65				9.17
1728	48.89	16	55.83	15	53.33	16	43.00	18	0.00	0	0.00	0	50.26	65				8.14
1729	59.28	16	51.89	13	51.39	13	72.28	11	0.00	0	0.00	0	58.71	53	356	1059		5.68
1730	37.06	21	48.39	22	34.72	23	42.78	24	0.00	0	0.00	0	40.74	90				13.90
1731	42.22	19	39.56	18	42.72	19	40.28	22	0.00	0	0.00	0	41.19	78				11.91
1732	35.28	15	58.28	13	37.28	21	35.67	21	0.00	0	0.00	0	46.62	70				9.45
1733	40.28	18	45.56	21	38.83	21	39.78	25	0.00	0	0.00	0	41.11	85				13.01
1734	35.39	22	45.33	19	48.00	22	35.56	22	0.00	0	0.00	0	41.07	85	408			13.02
1735	44.11	19	52.56	20	36.56	23	41.00	28	0.00	0	0.00	0	43.56	90				13.00
1736	32.28	23	36.22	22	44.56	20	50.22	19	0.00	0	0.00	0	40.82	84				12.95
1737	56.17	18	57.61	15	59.72	13	47.83	15	0.00	0	0.00	0	55.33	61				6.94
1738	53.22	14	51.33	18	45.39	16	43.17	15	0.00	0	0.00	0	48.78	63				8.13
1739	42.17	26	41.28	21	44.67	21	54.11	17	0.00	0	0.00	0	45.56	85				11.74
1740	***NO DATA***																	
1741	52.67	15	57.39	16	38.56	20	43.89	21	0.00	0	0.00	0	48.12	72				9.41
1742	43.56	21	44.39	22	40.56	23	35.56	23	0.00	0	0.00	0	41.01	89				13.65
1743	39.39	28	37.17	26	34.78	27	30.78	27	0.00	0	0.00	0	35.53	108				19.13
1744	26.33	29	35.50	29	30.22	26	32.06	26	0.00	0	0.00	0	31.03	110	486	1272		22.31
1745	33.22	28	35.06	24	37.70	27	40.67	28	0.00	0	0.00	0	36.68	107				19.35
1746	31.67	30	35.83	29	32.78	29	40.89	29	0.00	0	0.00	0	35.29	117				20.86
1747	29.22	32	23.89	27	26.78	28	28.00	29	0.00	0	0.00	0	27.47	116				26.57
1748	44.41	29	31.67	25	34.83	27	30.56	23	0.00	0	0.00	0	35.42	95				16.08
1749	55.11	11	40.72	16	55.56	11	34.50	25	0.00	0	0.00	0	45.97	63	461			6.62
1750	47.39	17	47.61	18	36.06	17	48.94	18	0.00	0	0.00	0	46.00	70				9.57
1751	40.00	26	44.17	22	45.61	20	42.89	23	0.00	0	0.00	0	43.17	91				13.26
1752	20.83	27	31.61	29	37.78	28	33.67	28	0.00	0	0.00	0	33.72	111				20.71
1753	26.72	30	29.78	28	23.67	26	25.94	29	0.00	0	0.00	0	26.40	113				26.93
1754	23.11	31	24.50	33	20.61	26	26.22	30	0.00	0	0.00	0	24.11	120	549			31.31
1755	23.94	30	24.67	[illegible]	22.94	28	20.39	27	0.00	0	0.00	0	22.99	114				31.20
1756	24.06	30	23.33	30	19.11	25	23.67	29	0.00	0	0.00	0	23.04	114				31.13
1757	27.78	31	23.67	29	21.67	29	17.61	24	0.00	0	0.00	0	22.56	113				31.52
1758	***NO DATA***																	
1759	18.33	36	16.78	30	19.17	[illegible]	14.00	30	0.00	0	0.00	0	17.32	122	591	[illegible]	4909	44.37
1800	16.11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.03	30	0.00	0	0.00	0	10.03	116				40.10
		176		[illegible]		550		1005		0		0		4075	45 MIN TOTAL			
		5556		[illegible]		[illegible]		1158		0		0		19009	ACCUM TOTAL			

Figure 20

Missing ramp data for both Los Angeles and San Diego were generated using the following methods. If the ramp was missing for the duration of the test period, then average daily traffic (ADT) data were used to generate the necessary volumes. ADT data from 1984 RAMP VOLUMES ON THE CALIFORNIA FREEWAY SYSTEM were compared with our 1985 measured volume data to establish a growth factor between 1984 and 1985. This was used to predict the 1985 ADT for the missing ramps from their 1984 values. Five minute volumes were derived from this ADT by following a similar time-volume distribution as at the adjacent ramps. The second method involved sites that had random holes in the measured data. The missing data were calculated by averaging the measured data from other runs for the location and the time in question.

A third method of generating missing data was developed specifically for the Hwy 125 off-ramp in San Diego. Due to its recent construction, no loop detectors were functioning and no ADT data were available for this ramp. The known main line volume data upstream and downstream from Hwy 125 were used to calculate Hwy 125's missing data.

ADT data for Hwy 67 could not be used because the volumes on the ramp had changed significantly between 1984 and 1985 . A correlation between 1985 data and 10/7/86 data was found and used to calculate the 1985 data for this ramp.

Adjustments were made at some locations to simplify the ramp volume data analysis. In some cases where two ramps for a cross street were proximate, data were summed and treated as one ramp. The data from the two San Diego on-ramps, Farmont and Texas, were summed due to their close proximity. Two San Diego off-ramps where we had no data, Grossmont and Jackson, were assumed to have zero volumes due to their low volume.

Lane one of Fuerte main line and lane three of Second main line in San Diego were missing throughout the research period and were calculated using downstream and known lane volumes.

Some of the measured main line Los Angeles data were found to be inconsistent with upstream and downstream volumes. These volume data were left in the final data base, but were flagged as being possibly error-prone in the traffic volume error array. These locations included AM southbound Melrose which had low volumes, PM southbound Melrose which had high volumes, and PM southbound Silver Lake which had high volumes.

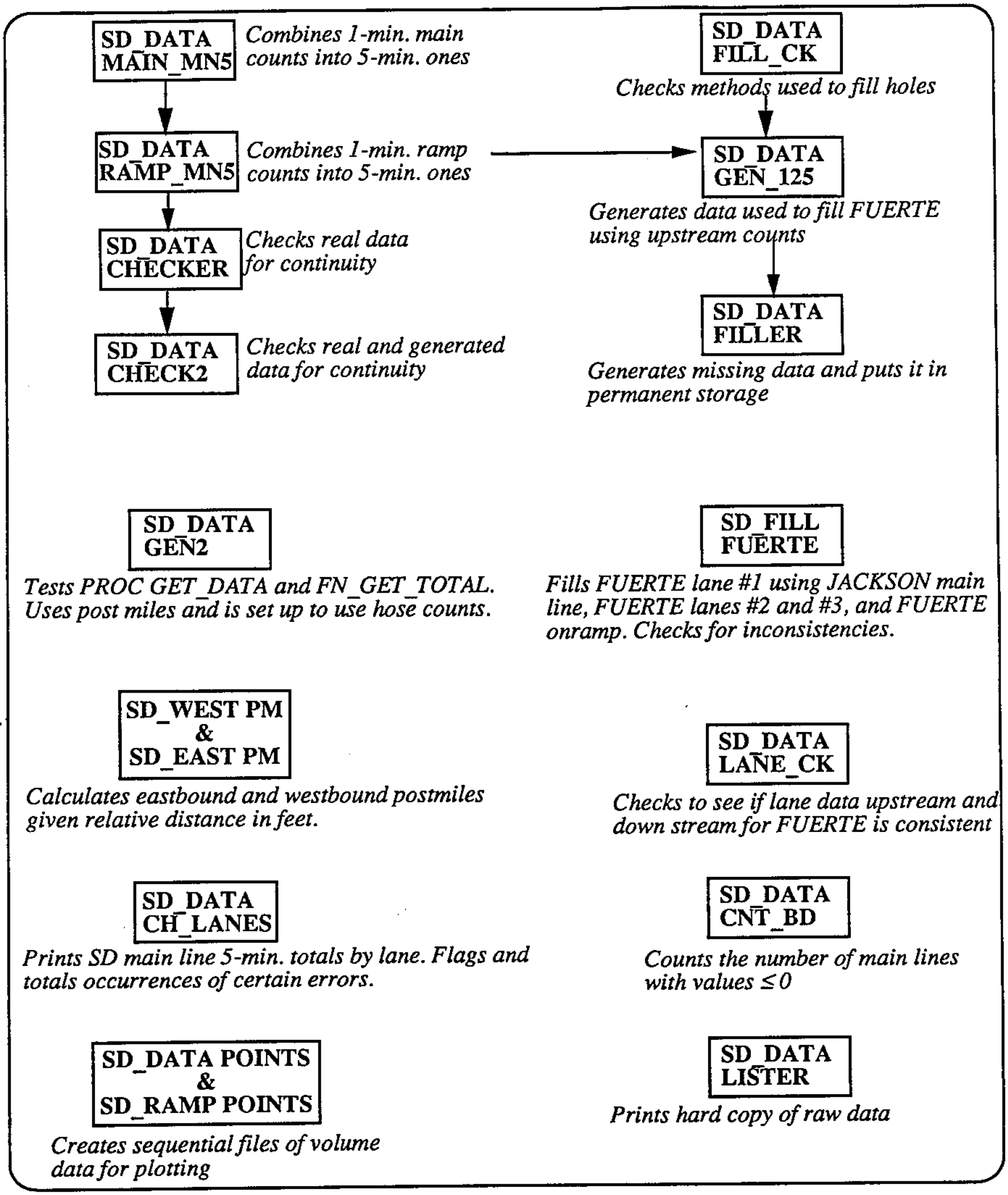
This raw data was fed into a large array - dimensioned by date, period, direction, time, lane and location. The Los Angeles main line data were in one-minute-counts per lane, so this was summarized into five-minute counts to make it consistent with the hose counter time interval used for the ramps. Individual lane volumes that were missing were generated by either averaging adjacent lanes within that time period or averaging the same lane counts from adjacent time periods. The individual lane volumes were then added to obtain a total main line volume for every five-minute period.

Once 5 minute volumes were collected for each main line section and ramp where there was a detector, the other main line and ramp volumes were generated by adding/subtracting adjacent ramps. For example, if one main line section had a detector and an adjacent downstream one did not, the adjacent section volume could be generated by adding the on-ramp volume to the detector volume. In this way the volumes for all of the main line sections between ramps (hereafter referred to as links) and the ramps themselves could be calculated. This did leave some main line links where the traffic volumes were calculated from detectors that were up to a mile away. Ramp volumes calculated by subtracting adjacent main line volumes sometimes appeared invalid due to the much larger relative magnitude (and errors) in the main line volumes.

An error array was created with the same dimension as the main line and ramp volume arrays. Different error codes indicate such things as how the data were generated, and sometimes a qualitative assessment of whether it is considered too high or too low. A separate numeric array was used for main line volumes to indicate 1) if it was taken directly from a detector, 2) generated from a detector and ramp data but could not be checked or 3) could be calculated in two directions, (i.e. from a detector and ramp upstream and a detector and ramp downstream). In this last case the numerical value of the difference between the two calculations was stored in this array to give some indication of the validity of the numbers. The value stored in the actual volume array was always the one that was calculated from the main line detector that was the least number of ramps from the desired main line link.

Figure 21 briefly describes some of the programs used to analyze the traffic volume data for San Diego.

Programs Used To Set Up San Diego Volume Data



All programs written in Waterloo Basic running under the CMS operating system on an IBM 4341 mainframe

Figure 21

After all the various manipulations of the volume data had taken place, there was a need to analyze the aggregate data base for continuity. A graphical method for displaying a full (AM or PM) period's volume density data was developed to aid in this analysis. These volume density plots are shown in Appendix C. An example is given in Figure 22. Displaying the data in this fashion helped us to quickly and easily check for continuity and validity and to visualize how the traffic volume was changing with time and distance.

5.2 VEHICLE DATA

All vehicle data were downloaded from the data logger to an Apple Macintosh microcomputer. Here it was broken into separate distance, fuel, and event files. Whenever the data logger received a distance of 10 feet, it would record it as "0" due to an error in the recorder hardware. Therefore, an algorithm was written to look at all "0" values and determine if they were legitimate "0"s, or if they should have been "10"s. Basically the sequence of speeds was analyzed and if the speeds surrounding the "0" value were "non 0", then a value of "10" was substituted in the data file. This algorithm required some "tweaking" to get it so that the summation of the distance file for any given run exactly equalled the distance manually recorded from the DMI. No data dropouts were noted for the fuel values.

Once the data were run through various checking and validation programs, all the various runs for a specific area, time period, and direction were combined to produce a contour plot of speed on a time-distance axis. See Figure 23 and Appendix D. The method used to produce these plots is a computerized version of a method originally developed by the Los Angeles Caltrans (District 07) Office. This method is briefly explained in Appendix E. These were used to get a aggregate view of the traffic speed over the entire project for a specific period. This made it easier to do continuity and validation checks as the data were further broken up and processed. These plots were produced at the same scale as the volume density plots. This plotting method has been incorporated into the California Highway Congestion Monitoring Program described in Appendix B.

In its final format, the data were chopped up into files, runs, and links. A file is defined as all the data generated by each vehicle for any period (AM or PM) for any day. Each file is broken up into different runs, which are defined as one specific continuous trip in a file. Each run is broken into links, where the link boundaries are defined as the points where main line traffic volume makes a significant change (an on-ramp or off-ramp gore point).

Volume Density Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/11/85 - Upper Plot 04/12/85 - Lower Plot

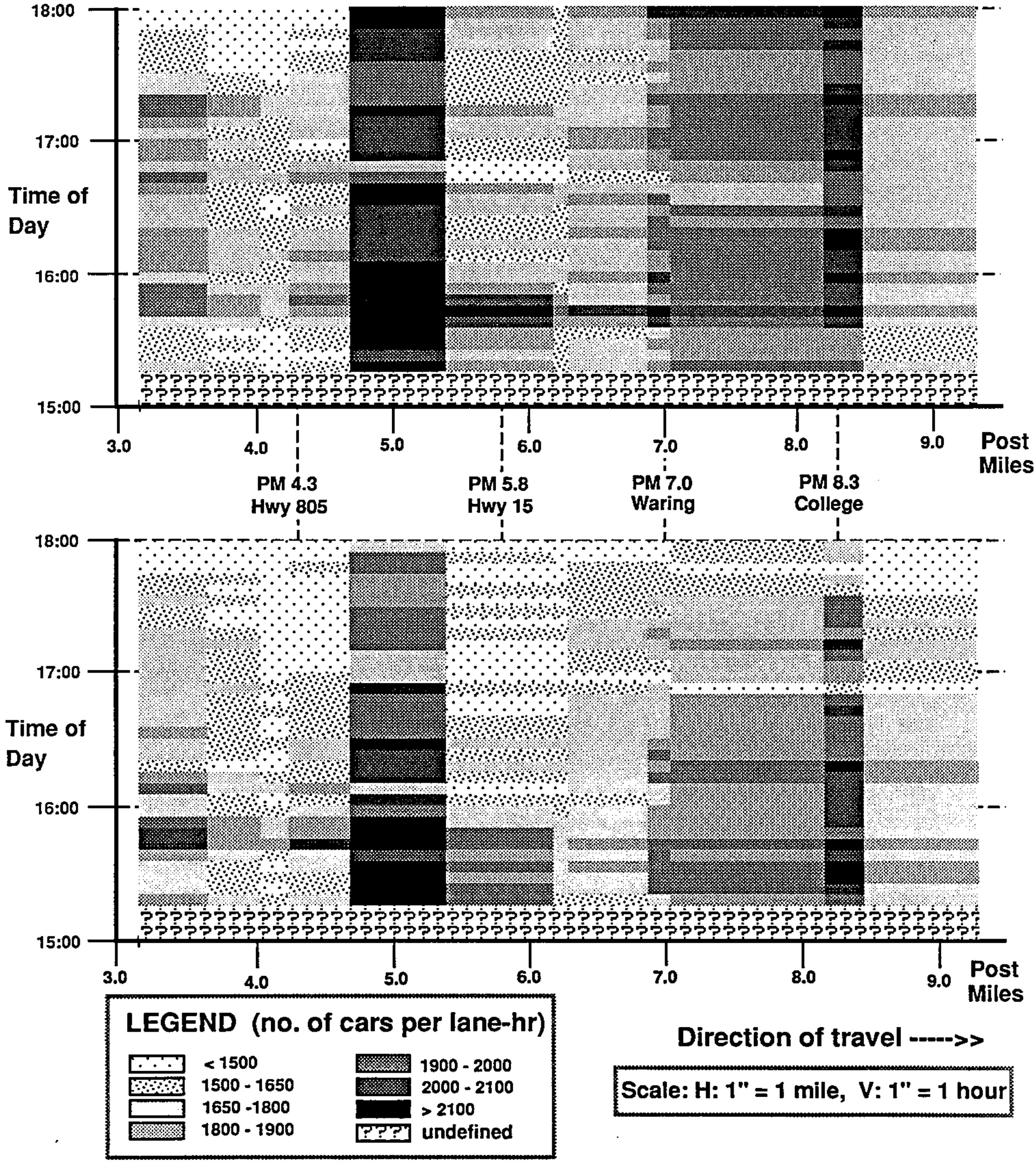


Figure 22

Speed Contour Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/11/85 - Upper Plot 04/12/85 - Lower Plot

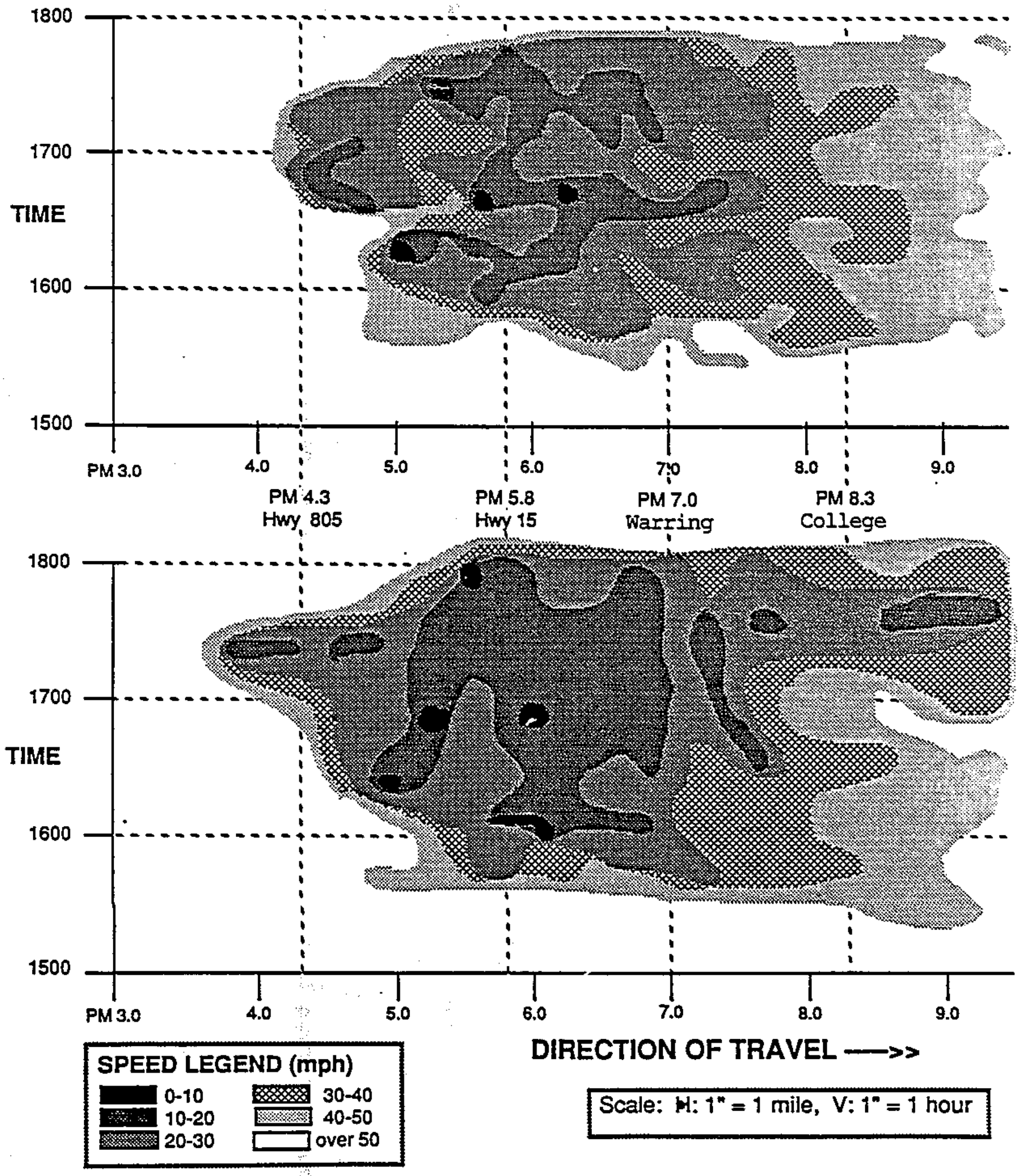


Figure 23

The major congestion in San Diego (files 1 through 31) was unidirectional so that all the data for a specific file was in one direction. This means that there was only one set of geometrics associated with each file in San Diego. For the Hollywood Freeway in Los Angeles, (files 102 through 134) congestion was often bidirectional so that any specific file had runs in both directions. For Los Angeles, all the odd numbered runs were in the south direction and the even runs in the north direction. Figure 24 and 25 provide more file-specific information.

The vehicle data were transferred run by run to the mainframe for analysis by the program VEHC.

File Information for Los Angles Files

File#	Location	Direction	Day	Date	Period	Driver#	Car
102	LA-101	NB & SB	Monday	5/13/85	PM	1	Silver
103	LA-101	NB & SB	Tuesday	5/14/85	AM	1	Silver
104	LA-101	NB & SB	Tuesday	5/14/85	AM	3	Brown
105	LA-101	NB & SB	Tuesday	5/14/85	PM	1	Silver
106	LA-101	NB & SB	Tuesday	5/14/85	PM	3	Brown
107	LA-101	NB & SB	Wednesday	5/15/85	AM	1	Silver
108	LA-101	NB & SB	Wednesday	5/15/85	AM	3	Brown
109	LA-101	NB & SB	Wednesday	5/15/85	PM	1	Silver
110	LA-101	NB & SB	Wednesday	5/15/85	PM	3	Brown
111	LA-101	NB & SB	Thursday	5/16/85	AM	1	Silver
112	LA-101	NB & SB	Thursday	5/16/85	AM	3	Brown
113	LA-101	NB & SB	Thursday	5/16/85	PM	1	Silver
114	LA-101	NB & SB	Thursday	5/16/85	PM	3	Brown
115	LA-101	NB & SB	Friday	5/17/85	AM	1	Silver
116	LA-101	NB & SB	Friday	5/17/85	PM	1	Silver
117	LA-101	NB & SB	Monday	5/20/85	AM	1	Silver
118	LA-101	NB & SB	Monday	5/20/85	AM	3	Brown
119	LA-101	NB & SB	Monday	5/20/85	PM	1	Silver
120	LA-101	NB & SB	Monday	5/20/85	PM	3	Brown
121	LA-101	NB & SB	Tuesday	5/21/85	AM	1	Silver
122	LA-101	NB & SB	Tuesday	5/21/85	AM	3	Brown
123	LA-101	NB & SB	Tuesday	5/21/85	PM	1	Silver
124	LA-101	NB & SB	Tuesday	5/21/85	PM	3	Brown
125	LA-101	NB & SB	Wednesday	5/22/85	AM	1	Silver
126	LA-101	NB & SB	Wednesday	5/22/85	AM	3	Brown
127	LA-101	NB & SB	Wednesday	5/22/85	PM	1	Silver
128	LA-101	NB & SB	Wednesday	5/22/85	PM	3	Brown
129	LA-101	NB & SB	Thursday	5/23/85	AM	1	Silver
130	LA-101	NB & SB	Thursday	5/23/85	AM	3	Brown
131	LA-101	NB & SB	Thursday	5/23/85	PM	1	Silver
132	LA-101	NB & SB	Thursday	5/23/85	PM	3	Brown
133	LA-101	NB & SB	Friday	5/24/85	AM	1	Silver
134	LA-101	NB & SB	Friday	5/24/85	AM	3	Brown

Figure 24

File Information for San Diego Files

File#	Location	Direction	Day	Date	Period	Driver#	Car
1	SD-8	WB	Tuesday	4/9/85	AM	1	Silver
2	SD-8	WB	Tuesday	4/9/85	AM	2	Brown
3	SD-8	EB	Tuesday	4/9/85	PM	1	Silver
4	SD-8	EB	Tuesday	4/9/85	PM	2	Brown
5	SD-8	WB	Wednesday	4/10/85	AM	1	Silver
6	SD-8	EB	Wednesday	4/10/85	PM	2	Brown
7	SD-8	EB	Wednesday	4/10/85	PM	1	Silver
8	SD-8	WB	Thursday	4/11/85	AM	1	Silver
9	SD-8	WB	Thursday	4/11/85	AM	2	Brown
10	SD-8	EB	Thursday	4/11/85	PM	1	Silver
11	SD-8	EB	Thursday	4/11/85	PM	2	Brown
12	SD-8	WB	Friday	4/12/85	AM	1	Silver
13	SD-8	WB	Friday	4/12/85	AM	2	Brown
14	SD-8	EB	Friday	4/12/85	PM	1	Silver
15	SD-8	EB	Friday	4/12/85	PM	2	Brown
16	SD-8	WB	Monday	4/15/85	AM	1	Silver
17	SD-8	WB	Monday	4/15/85	AM	2	Brown
18	SD-8	EB	Monday	4/15/85	PM	1	Silver
19	SD-8	WB	Tuesday	4/16/85	AM	1	Silver
20	SD-8	WB	Tuesday	4/16/85	AM	2	Brown
21	SD-8	EB	Tuesday	4/16/85	PM	1	Silver
22	SD-8	WB	Wednesday	4/17/85	AM	1	Silver
23	SD-8	WB	Wednesday	4/17/85	AM	2	Brown
24	SD-8	EB	Wednesday	4/17/85	PM	1	Silver
25	SD-8	WB	Thursday	4/18/85	AM	1	Silver
26	SD-8	WB	Thursday	4/18/85	AM	2	Brown
27	SD-8	EB	Thursday	4/18/85	PM	1	Silver
28	SD-8	WB	Friday	4/19/85	AM	1	Silver
29	SD-8	WB	Monday	4/22/85	AM	1	Silver
30	SD-8	EB	Monday	4/22/85	PM	1	Silver
31	SD-8	WB	Tuesday	4/23/85	AM	1	Silver

Figure 25

6. THE VEHC PROGRAM

6.1 GENERAL DESCRIPTION

The FHWA's VEHC program represents the latest state of the art in computerized vehicle fuel consumption models. It contains a data base of fuel consumption vs speed and acceleration for 15 different vehicles. These 15 vehicles were carefully selected from the available vehicles in 1982 as representing the future vehicle fleet.

The VEHC model was not made to be a stand-alone program. The benefits of its fuel consumption predictive capability are used by other computer programs, such as NETSIM, TRANSIT, SOAP, etc., (17). We had to modify the program's output capabilities to make it compatible with this analysis.

The VEHC program itself consists of 3,660 lines of Fortran source code. It requires a continuous description of the velocity and grade profile, with a one-second time step. Associated with it are a number of modules and utilities that aid in its operation, such as creating the roadway profile, trip definition, or mixing the vehicles in the vehicle fleet. It also has the capacity to predict the quantities of air pollution generated by four of the 15 vehicle types, although we did not utilize this capability (18).

The data base, for the fuel consumption values the VEHC program uses, was created by a series of computer programs. Basically, two sets of tests were performed for each of the 15 vehicles. The first tests were performed on a chassis dynamometer where the fuel consumption was recorded as a function of engine RPM and intake manifold. The second set of tests developed a data base of the engine RPM and intake manifold as a function of vehicle speed, acceleration, and transmission gear. The data bases were combined by computer to produce the final data base of fuel consumption as a function of speed and acceleration.

Although the above method is conceptually valid, it did yield some strange results. For example, the percent change in the fuel consumption rate between 50 and 60 mph ranged from 6% for a 1982 Toyota Corolla to 41% for a 1981 Datsun 210 (10). This would seem to be a large variation in a key fuel consumption parameter for two vehicles with otherwise similar characteristics. However, this data base does represent the most complete fuel consumption analysis tool available at this time.

6.2 ANALYSIS METHOD

The VEHC program can model up to 15 vehicles. To test the validity of the model, we took the one vehicle (the 1982 Citation) that was the closest to our test vehicles (1980 Citations) and evaluated it to see if it followed the same fuel consumption characteristics as our test vehicles in traffic. If it did, then we could infer (but not prove) that the model performs correctly in traffic and that by using the 15 vehicles we could get a composite vehicle that had the same relativistic fuel consumption relationships as the true on-the-road fleet.

The VEHC program was run for two vehicle types: the 1982 fuel injected Citation and a composite "fleet" vehicle combined using various percentages of each of the 15 vehicle types. These percentages were provided by the Alberto Santiago of the FHWA and are shown in Figure 26, below.

FHWA Vehicle Fleet Composition

Vehicle	Engine Size	# Cylinders	% of Fleet
Fairmont	2.3	4	7.90%
Citation	2.5	4	3.50%
Futura	3.3	6	1.70%
Plym Reliant	2.6	4	1.10%
Toyota Corolla	1.8	4	4.20%
Ford Escort	1.6	4	5.80%
Pontiac	2.8	6	6.30%
Monte Carlo	3.75	6	1.40%
Chevette Diesel	---	4	0.80%
Capri Diesel	5.7	8	2.00%
Chev Pickup	6.2	8	0.30%
Datsun	1.5	4	3.40%
Capri Gas	5.0	8	46.80%
Buick Century	3.8	6	11.10%
Chev Pickup	2.0	-	3.70%
	Total		100.00%

Figure 26

Every run of every file of the distance data generated by our 1980 Citations was processed through the VEHC program, using the appropriate geometric files and ambient temperature values. This generated second-by-second fuel consumption values for each of the two vehicle types described above.

6.3 VEHC FUEL CONSUMPTION VS MEASURED FUEL CONSUMPTION

One of the first things we noted was that VEHC predicts significantly higher fuel consumption for the 1982 Citation than we measured for our 1980 Citation. This was true for both constant-speed and high-acceleration/deceleration situations. The magnitude of this was significantly greater than the 1 to 3% error noted in our fuel measurement equipment.

A potential reason for the VEHC overprediction of fuel consumption was thought to be due to the model's need for higher resolution data than we were able to supply to it. The velocity profiles we collected only had a 1 ft/sec resolution. This means if the vehicle were traveling at a constant 70.5 ft/sec, the speed would be recorded as 70, 71, 70, 71, etc.... VEHC would consider this a series of acceleration/deceleration cycles, and therefore, overpredict the fuel consumption.

Figure 27 shows the variation of the real fuel consumption at constant speed due to fuel fluctuations in the carburetor bowl. It also shows the fuel and distance changing in discrete quanta due to lack of resolution of our instrumentation. Figure 28 shows that VEHC predicts a much larger fuel consumption (in both relative and absolute magnitude) for this same speed profile.

We tested the effect of the lack of our instrument resolution by running a series of smoothing algorithms on the speed data before cranking it through VEHC. This was first attempted by taking a two- and three-second moving average of the speed data. However, this method also had the side effect of rounding off the acceleration spikes due to the heavy transients during congestion.

Therefore, we modified this smoothing algorithm so that it would only produce a moving average if the change in speed between two adjacent measurements was less than or equal to two values: 2 ft/sec and 3 ft/sec. This smoothing algorithm analysis was performed on four files. The results of one of these files is shown in Figure 29. A composite of the VEHC to measured fuel ratios is shown in Figure 30.

These speed smoothing methods did reduce the VEHC to measured fuel consumption ratio by 5% to 15%. However, the VEHC fuel consumption was still significantly higher than our measured values, so the method was not adopted in the final data base.

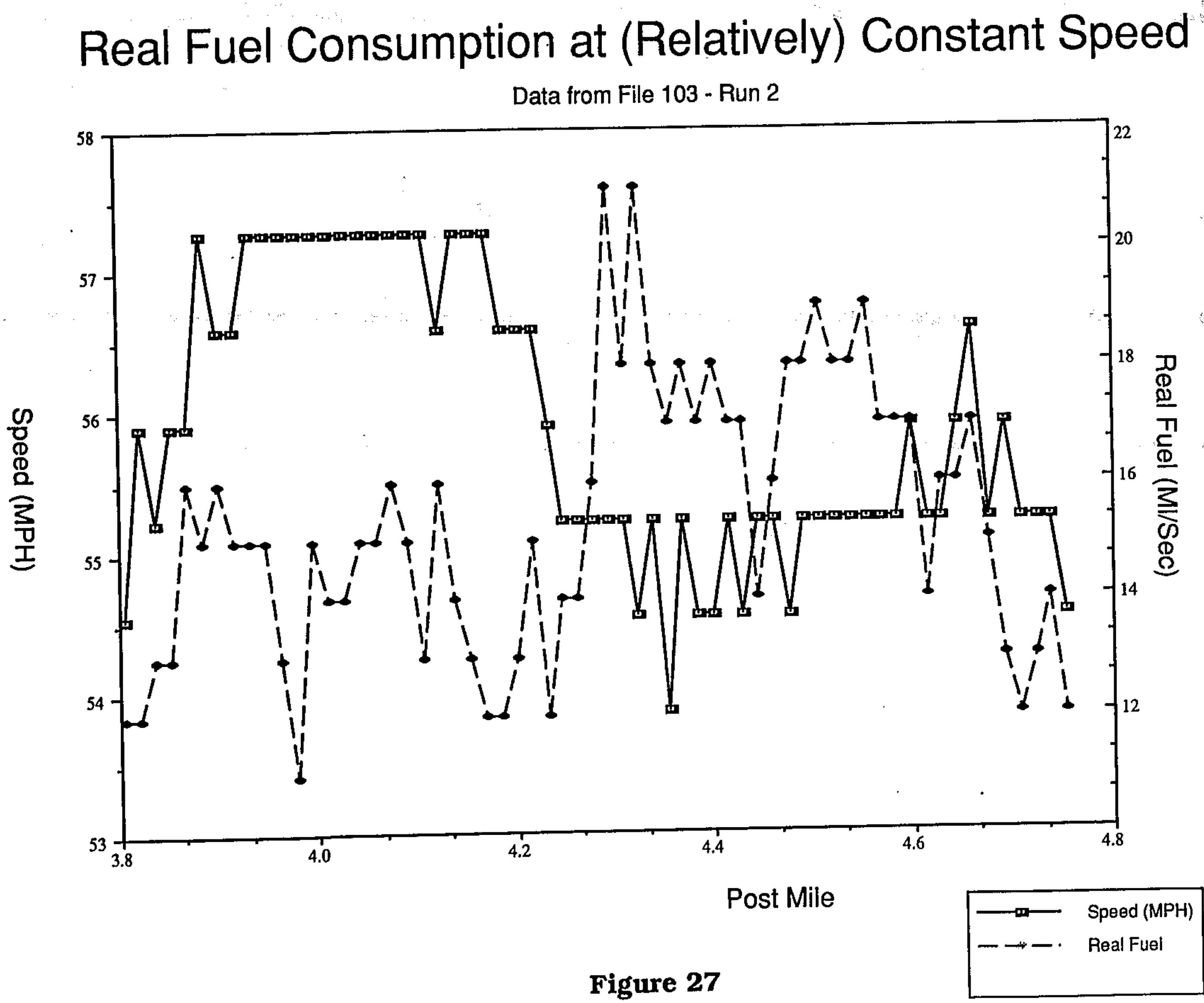

Real Fuel Consumption at (Relatively) Constant Speed
Data from File 103 - Run 2
Speed (MPH)
Real Fuel (Ml/Sec)
Post Mile
58
57
56
55
54
53
22
20
18
16
14
12
3.8
4.0
4.2
4.4
4.6
4.8
Speed (MPH)
Real Fuel

Figure 27

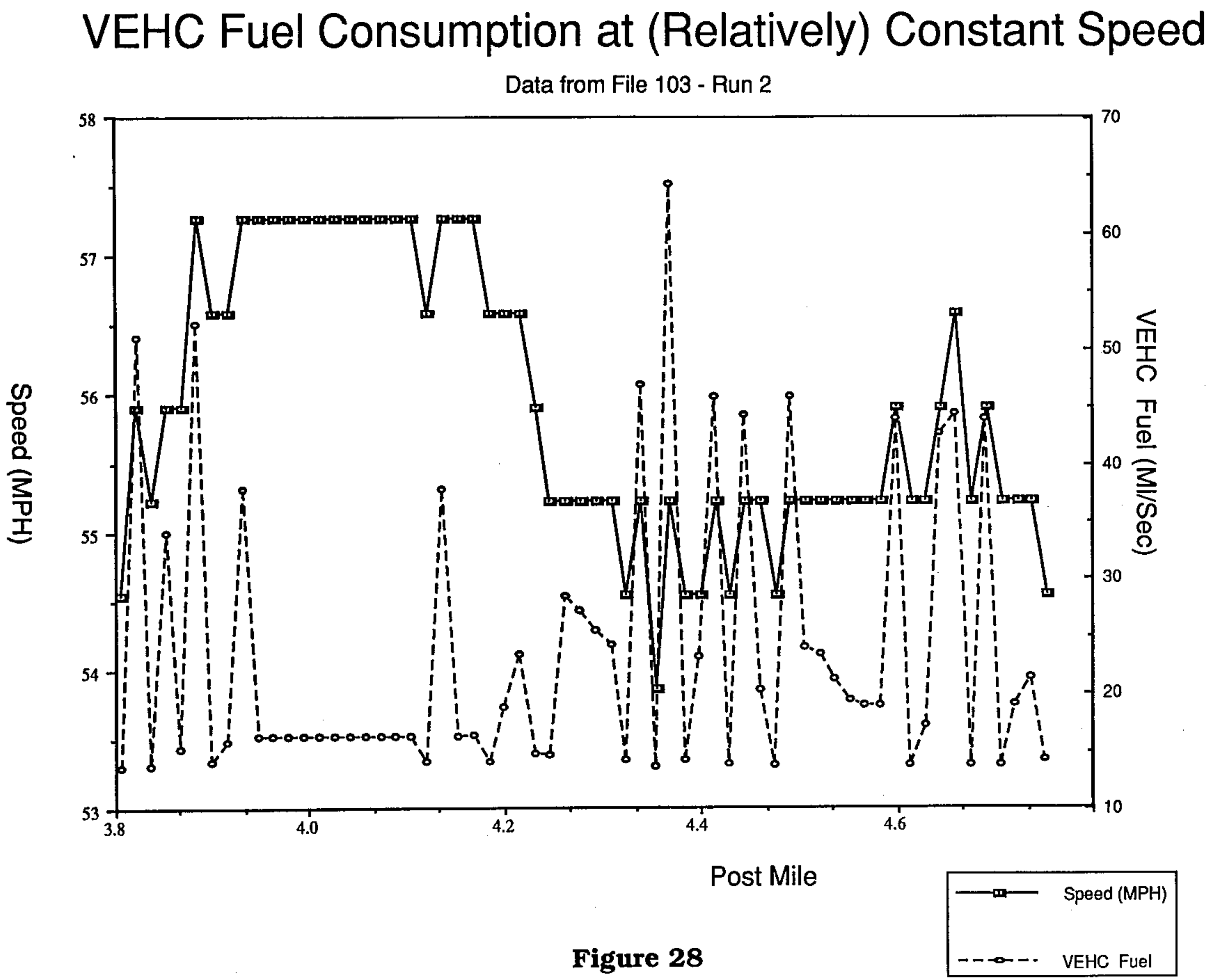

VEHC Fuel Consumption at (Relatively) Constant Speed
Data from File 103 - Run 2
58
57
56
55
54
53
Speed (MPH)
70
60
50
40
30
20
10
VEHC Fuel (Ml/Sec)
3.8
4.0
4.2
4.4
4.6
Post Mile
Speed (MPH)
VEHC Fuel

Figure 28

Effect of Smoothing Algorithms on VEHC/Real Citation Fuel Consumption Ratios

Data for File 114

Raw Data

Run #	Speed (MPH): Measured Speed	Speed (MPH): 2 Point (2 MPH Max)	Speed (MPH): 2 Point (3 MPH Max)	Speed (MPH): 3 Point (2 MPH Max)	Speed (MPH): 3 Point (3 MPH Max)	Fuel (Liters): Measured Fuel	Fuel (Liters): 2 Point (2 MPH Max)	Fuel (Liters): 2 Point (3 MPH Max)	Fuel (Liters): 3 Point (2 MPH Max)	Fuel (Liters): 3 Point (3 MPH Max)	VEHC/Measured Fuel Ratio: 2 Point (2 MPH Max)	VEHC/Measured Fuel Ratio: 2 Point (3 MPH Max)	VEHC/Measured Fuel Ratio: 3 Point (2 MPH Max)	VEHC/Measured Fuel Ratio: 3 Point (3 MPH Max)
1	26.1	26.2	26.2	26.2	26.2	.141	.226	.215	.221	.213	1.60	1.52	1.57	1.51
2	51.8	51.9	51.9	51.9	51.9	.084	.125	.120	.121	.118	1.49	1.43	1.44	1.40
3	22.2	22.3	22.4	22.3	22.3	.161	.263	.253	.258	.250	1.63	1.57	1.60	1.55
4	52.5	52.5	52.5	52.5	52.5	.084	.132	.126	.127	.123	1.57	1.50	1.51	1.46
5	53.0	53.2	53.2	53.2	53.2	.118	.193	.189	.189	.186	1.64	1.60	1.60	1.58
6	51.4	51.4	51.4	51.4	51.4	.087	.128	.123	.125	.121	1.47	1.41	1.44	1.39
7	57.6	57.6	57.6	57.6	57.6	.113	.179	.175	.175	.173	1.58	1.55	1.55	1.53
8	44.0	44.2	44.1	44.1	44.1	.089	.142	.137	.136	.135	1.60	1.54	1.53	1.52
9	49.3	49.4	49.4	49.4	49.4	.126	.192	.187	.188	.185	1.52	1.48	1.49	1.47
10	38.1	38.3	38.3	38.3	38.3	.109	.166	.162	.162	.161	1.52	1.49	1.49	1.48
11	59.8	59.9	59.9	59.9	59.9	.123	.185	.180	.181	.178	1.50	1.46	1.47	1.45
12	26.0	26.1	26.1	26.0	26.1	.111	.181	.174	.175	.171	1.63	1.57	1.58	1.54

Summary Data

		2 Point (2 MPH Max)	2 Point (3 MPH Max)	3 Point (2 MPH Max)	3 Point (3 MPH Max)
South Bound	Mean of FC ratios ($\overline{X}$)	1.58	1.53	1.55	1.52
	Standard Deviation (σ)	.057	.054	.055	.049
	Percentage Std. Dev (σ %)	3.6%	3.5%	3.6%	3.2%
North Bound	Mean of FC ratios ($\overline{X}$)	1.55	1.49	1.50	1.46
	Standard Deviation (σ)	.063	.062	.054	.061
	Percentage Std. Dev (σ %)	4.1%	4.1%	3.6%	4.2%
All Runs	Mean of FC ratios ($\overline{X}$)	1.56	1.51	1.52	1.49
	Standard Deviation (σ)	.060	.059	.058	.059
	Percentage Std. Dev (σ %)	3.8%	3.9%	3.8%	4.0%

Note : Southbound Runs Marked With Shading

Figure 29

Effect of Smoothing Algorithms on VEHC/Real Citation Fuel Consumption Ratios

Summary of 4 Files

(Mean and Standard Deviation of Ratios)

File	1 Point		2 Point		3 Point		2 Point (2 MPH Max)		2 Point (3 MPH Max)		3 Point (2 MPH Max)		3 Point (3 MPH Max)	
	$\bar{X}$	$\bar{\sigma}$%	$\bar{X}$	$\bar{\sigma}$%	$\bar{X}$	$\bar{\sigma}$%	$\bar{X}$	$\bar{\sigma}$%	$\bar{X}$	$\bar{\sigma}$%	$\bar{X}$	$\bar{\sigma}$%	$\bar{X}$	$\bar{\sigma}$%
113 SB	1.79	3.2	1.65	1.5	1.54	5.4	1.71	4.0	1.67	3.5			1.64	2.6
NB	1.72	1.6	1.53	2.5	1.44	5.4	1.61	2.7	1.54	3.6			1.50	3.4
ALL	1.75	3.2	1.59	4.3	1.49	6.2	1.66	4.5	1.61	5.4			1.57	5.6
114 SB	1.65	2.5	1.53	3.2			1.58	3.6	1.53	3.5	1.55	3.6	1.52	3.2
NB	1.62	2.8	1.49	3.2			1.55	4.1	1.49	4.1	1.50	3.6	1.46	4.2
ALL	1.64	2.7	1.51	3.3			1.56	3.8	1.51	3.9	1.52	3.8	1.49	4.0
117 SB	1.78	2.5	1.39	5.2			1.71	2.6	1.66	2.9	1.64	2.6	1.61	3.1
NB	1.71	4.3	1.59	4.6			1.59	4.0	1.54	4.0	1.53	4.5	1.50	4.6
ALL	1.75	3.9	1.46	6.6			1.65	4.9	1.60	5.1	1.59	5.0	1.55	5.2
126 SB	1.67	2.6	1.54	3.1			1.61	3.7	1.56	3.9	1.57	4.5	1.53	4.5
NB	1.73	2.3	1.59	2.1			1.62	1.8	1.58	2.3	1.59	1.9	1.55	1.6
ALL	1.69	3.0	1.56	3.1			1.61	2.9	1.57	3.2	1.58	3.5	1.54	3.4

$\bar{X}$ = Mean of FC ratios $\bar{\sigma}$% = Average Standard Deviation (%)

The number of points (2 or 3) represent the number of values used in the moving average of the distance files before run through the VEHC program to determine fuel consumption. The maximum speed (2 or 3 MPH) represents the maximum speed change allowed for the moving average (i.e. if 2 consecutive speeds in a distance file were 4 ft/sec apart, then the actual values would be used rather than a moving average).

Figure 30

6.4 PROBLEMS WITH VEHC

A limitation of our measured fuel consumption data is that it is based on a mechanically carburetored vehicle rather than a fuel injected vehicle. The fuel was not measured as it was being consumed. The time lag due to the volume buffering effect on the fuel bowl can be up to a few seconds, so the second-by-second fuel consumption measured was not necessarily the same as that consumed. This is shown graphically in Figure 28.

Even in areas with high acceleration (where the absolute magnitude of acceleration is large relative to distance instrumentation resolution), VEHC seems to predict a much higher fuel consumption than the measured value. Due to the buffering effect of the fuel bowl, the overall effect of the large VEHC acceleration fuel consumption is difficult to determine by microscale analysis. However, using more aggregate statistics (say, a summation of 15 seconds or more) should get around the limitations caused by the differences in the two Citations' (VEHC and real) carburetors .

When VEHC is run for a composite vehicle, it apparently runs through the model once for each vehicle type and then combines the fuel consumption according to the percentage of each vehicle in the composite fleet. It also keeps the acceleration rate down to the rate that the least powerful vehicle can substantiate. For example, if our actual on-road tachograph had an acceleration from 2 to 9 ft/sec/sec, and the least powerful vehicle could only substantiate a 2 to 7 ft/sec/sec acceleration, then all vehicles would only be allowed a 2 to 7 ft/sec/sec acceleration. However, it would make up for this lost speed the first second that the acceleration rate didn't exceed the least powerful vehicle's capabilities. This situation happened at least a few times during each run and quite often during the heavy acceleration/deceleration of congested runs. Its net effect on the fleet fuel consumption is unknown, but is probably not substantial over all.

7. DATA BASE DESCRIPTION

The data produced as a result of this project have been reduced to two final data formats. The first format provides four values for every second of every run. The first value is speed in feet per second, the second is the measured fuel consumption for the 1980 Citations in tenths of a milliliter per second, the third is the VEHC 1982 Citation fuel consumption in tenths of a ml/sec, and the fourth is the VEHC fleet fuel consumption in tenths of a ml/sec. The file naming nomenclature is F(File#)_(Run#), where File# is the file number from 1 to 31 and 102 to 134. For example, file F102_2 represents the second run of file 102. There are a total of 581 data files in this format (one for each run). Each of these runs starts at the first designated post mile shown on the plan views (Figures 9 through 12) and continues until at least the last post mile shown for the last designated link.

The above data have been further reduced in the second link data base format. The fuel and distance data have been broken down into links, with other associated speed, traffic, and geometric data added. The final data base description is shown in Figure 31, below.

Link Data Base Directory

Field	Title	Units	Description
1	File	#	File #
2	Run	#	Run #
3	Link	#	Link #
4	Time	sec	Link travel time
5	Speed	MPH	Average link speed
6	Start Time	HH:MM	Real time of day
7	Real Fuel	GPM	Measured fuel for 1980 Citation
8	VEHC Cit Fuel	GPM	VEHC prediction for 1982 Citation
9	VEHC Flt Fuel	GPM	VEHC prediction for vehicle fleet
10	Accel	Ft/sec/sec	Total acceleration during link
11	Decel	Ft/sec/sec	Total deceleration during link
12	End Spd	MPH	Average speed for last 5 sec of link
13	Volume	Veh/lane/hr	Main line volume
14	R Vol	Veh/hr	Ramp volume
15	Range	#	Indicator of volume accuracy
16	Code	Alpha	Error codes
17	Type	Alpha	Ramp type (on,off)
18	Lanes	#	Number of main line lanes
19	Length	Miles	Link length
20	Merge Len	Miles	Merging length
21	Ele Up	Feet	Total change in elevation up
22	Ele Dn	Feet	Total change in elevation down
23	Grade	%	Average grade

Figure 31

8.0 DATA BASE ANALYSIS

Roughly 150 pages of analysis of the various aspects of the link data base were performed. Multiple correlations were made between the VEHC Citation and real fuel consumption holding various combinations of grade, speed, volume, acceleration and deceleration constant. Numerous correlations were done between speed, main line volume, ramp volume, and merging length.

Unfortunately, at the time this analysis were performed, the data base had not been thoroughly checked for errors and consistency. Numerous problems with the data base were discovered. Although approximately 96% of the data was valid, the 4% of the records which had some erroneous values disrupted the statistical validity of this analysis , rendering much of it invalid.

The majority of the final months spent on this project went into the final editing of this data base. At this time, error fields were added to the data base where the correct data could not be accurately resurrected. This final data base should be an accurate representation of the on-the-road conditions at the time data were collected. Unfortunately, little time was left to completely reanalyze the valid data's statistical trends. The most salient features of this lengthy first analysis are reproduced below, using the updated data base.

The initial data base analysis was broken down into two parts. First, an analysis was made of the VEHC Citation to real Citation fuel ratio. While it is acceptable that this ratio not be unity, it should remain more-or-less constant for changes in highway geometrics and traffic conditions. Second, once it was established that VEHC can adequately model the fuel consumption characteristics of this one vehicle type, the VEHC fleet fuel values would be used to generate generalized fuel maps for these different real highway geometric and traffic conditions.

8.1 ANALYSIS OF THE VEHC FUEL CONSUMPTION MODEL

There were approximately 100,000 individual speed and real fuel consumption readings gathered - for which there are corresponding VEHC Citation and fleet fuel values All of these data points are available in their original one value per second resolution. However, it is difficult to do an analysis on this many data points, especially when we don't expect a one-to-one correlation between the VEHC and real fuel values due to the carburetor (fuel bowl vs fuel injection) differences.

The first first attempt at analysis of the (VEHC Citation / real Citation) ratio was performed by aggregating it by both both run and file. Each run had 300 to 1000 readings each, while the files had approximately 5000 to 10,000 readings. The results of this are shown in figures 29 and 30. Although this does yield an average fuel consumption correction factor, it is impossible to break this down into the individual effects of important parameters , such as grade or acceleration.

Through analysis of the data base broken down into links, it is possible to isolate these important factors. It should be noted that this data base was divided into links based on a change in traffic volume, which has no (direct) bearing on fuel consumption. This leaves some links with as few as 4 individual readings (i.e. they were 4 seconds long), and some with over 100 readings. However, it is at this level of aggregation that it is the most convenient to analyze the effects of such parameters as grade, acceleration, and driver.

Only a few of the more basic analyses are shown here. Grade and acceleration are the two parameters known to have the most significant effect on vehicle fuel consumption. Therefore, an analysis was made of their effect on VEHC output.

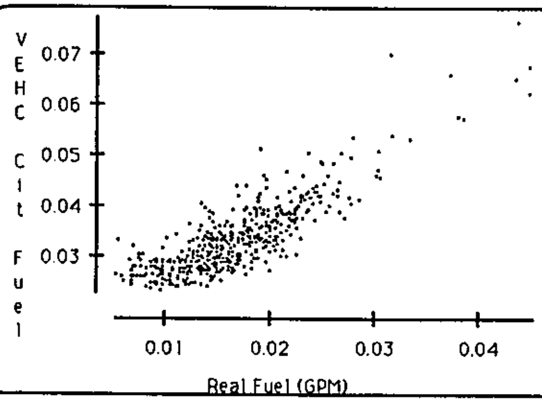
8.1.1 EFFECT OF GRADE

Figures 32 and 33 show the effect of grade on the correlation between the VEHC 1982 Citation fuel consumption and the (real) 1980 Citation. This shows that there is a definitive positive correlation between the VEHC computer output and measured fuel. It should be noted that this correlation is not expected to be perfect due to the differences between the 1982 (fuel injected) Citation and the 1980 (conventional fuel bowl carburetored) Citation.

These plots also show two interesting effects. 1) The slope of the VEHC vs real line is in the range of 1.36 to 1.49 except for the largest negative grades (of less than -2%) where it is 1.048. This indicates that VEHC may less significantly overpredict fuel at these negative grades. 2) The slopes of these plots appear to curve up at higher values, rather than being completely straight. This would indicate that VEHC tends to have a greater overprediction at larger values.

FUEL CONSUMPTION : VEHC vs REAL - NEGATIVE GRADES

GRADE LESS THAN -2%

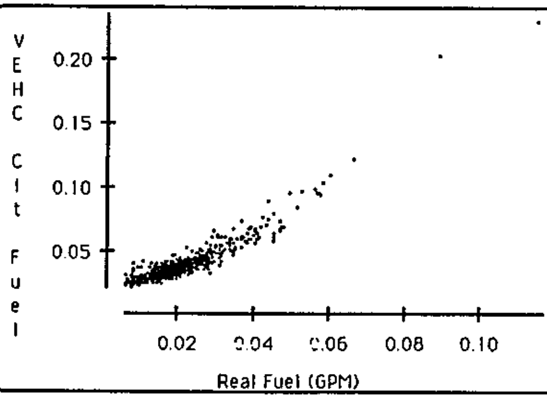


Dependent variable is: VECH Clt Fuel
R^2 = 72.2% R^2(adjusted) = 72.1%
s = 0.0039 with 454 - 2 = 452 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.018014	1	0.018014	1174
Residual	0.006933	452	0.000015	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.015855	0.0005	29.1
Real Fuel (GPM)	1.04857	0.0306	34.3

GRADE -2% TO -1%

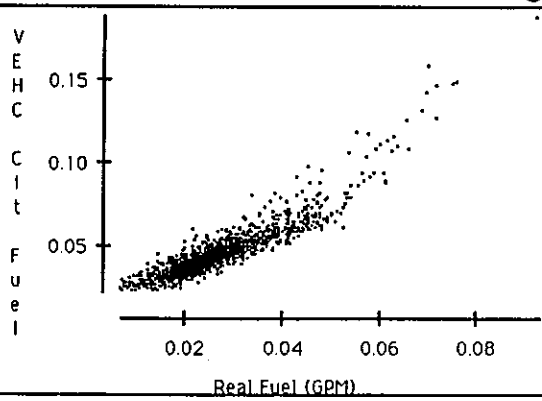


Dependent variable is: VECH Clt Fuel
R^2 = 83.9% R^2(adjusted) = 83.9%
s = 0.0058 with 831 - 2 = 829 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.144780	1	0.144780	4336
Residual	0.027682	829	0.000033	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.008690	0.0005	17.4
Real Fuel (GPM)	1.41712	0.0215	65.8

GRADE -1% TO 0%



Dependent variable is: VECH Clt Fuel
R^2 = 82.7% R^2(adjusted) = 82.7%
s = 0.0057 with 2090 - 2 = 2088 degrees of freedom

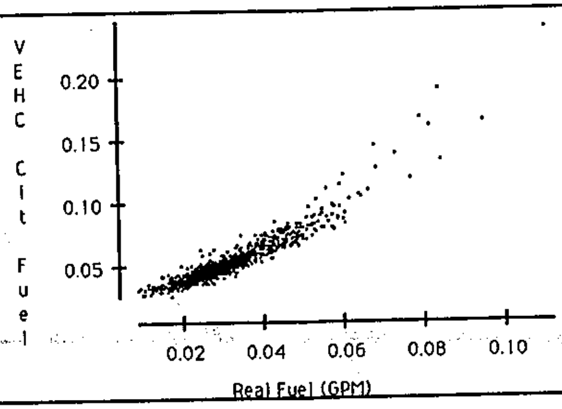
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.321005	1	0.321005	9980
Residual	0.067158	2088	0.000032	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.008300	0.0004	21.9
Real Fuel (GPM)	1.37904	0.0138	99.9

Figure 32

FUEL CONSUMPTION : VEHC vs REAL - POSITIVE GRADES

GRADE 0% TO 1%

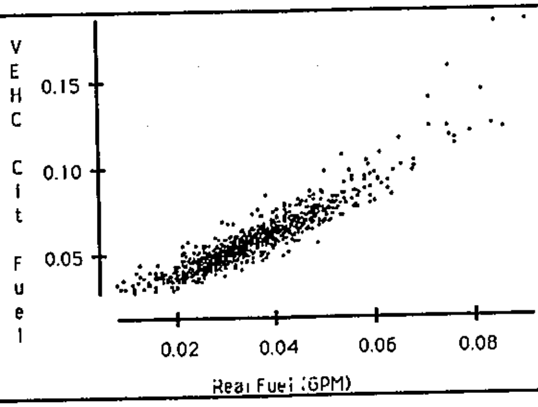


Dependent variable is: VECH Cit Fuel
R^2 = 87.5% R^2(adjusted) = 87.5%
s = 0.0056 with 1388 - 2 = 1386 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.308301	1	0.308301	9720
Residual	0.043963	1386	0.000032	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.005760	0.0005	11.8
Real Fuel (GPM)	1.49439	0.0152	98.6

GRADE 1% TO 2%

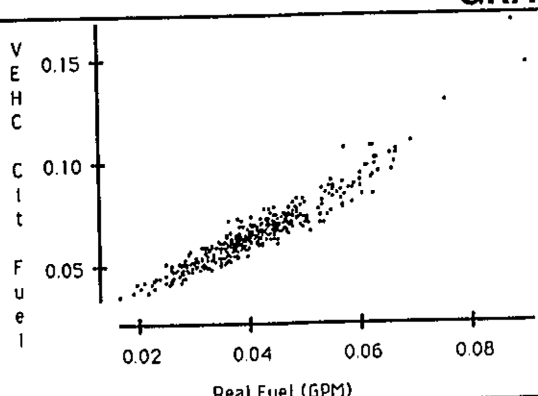


Dependent variable is: VECH Cit Fuel
R^2 = 86.1% R^2(adjusted) = 86.1%
s = 0.0059 with 1157 - 2 = 1155 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.250953	1	0.250953	7176
Residual	0.040392	1155	0.000035	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.009267	0.0006	15.7
Real Fuel (GPM)	1.36677	0.0161	84.7

GRADE GREATER THAN 2%



Dependent variable is: VECH Cit Fuel
R^2 = 89.9% R^2(adjusted) = 89.9%
s = 0.0045 with 458 - 2 = 456 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.083704	1	0.083704	4050
Residual	0.009424	456	0.000021	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.008169	0.0009	8.87
Real Fuel (GPM)	1.39496	0.0219	63.6

Figure 33

8.1.2 EFFECTS OF CAR, DRIVER AND LOCATION

The effects of driver and location were isolated to determine their effect on VEHC predictions. We expected to get different aggregate fuel consumption rates for each vehicle at the different locations because each location had different geometric conditions. San Diego has more dramatic grades and Los Angles has shorter merging lengths and sight distances. We also expected small differences in the fuel consumption rates with different drivers due to different personal driving technique, with some drivers tending to accelerate and decelerate faster then others in heavy traffic. However, in order for VEHC to be a useful model, it should be able to predict fuel consumption equally well over a wide range of driving conditions and geometrics and should yield a fairly constant VEHC to real Citation fuel ratio.

Additionally, it was useful to determine if there were any significant difference in the fuel consumption rates between the two identical (real) 1980 Citations. One of the basic tenets of the VEHC model is that the individual fuel consumption relationships of the 15 specific vehicles tested for the VEHC data base can be used to predict an entire vehicle fleet. Because the sample size is so small, it is important to assume 1) that the individual vehicle tested is representative of its class, and 2) that there would be little variation if another identical make and model vehicle were tested (i.e. the assumption must be made that the vehicle tested was not an outlier). Although neither of these assumptions can be thoroughly evaluated without an extremely large and expensive sample size, we can test the second assumption for the two Citations.

Because the two Citations were never traveling in the exact same place at the exact same time, we could not perform a paired statistical data analysis on the real fuel consumption values of these two data sets. However, an analysis can be made relative to the one thing that is held constant - the VEHC model. If the two individual vehicles did experience the exact same driving scenario on the same geometrics, VEHC would predict their fuel consumption to be the same. The VEHC-to-real fuel ratio would only be different if the two real Citations had different fuel consumption characteristics.

It should be noted only one driver was used for the silver Citation at both locations, while separate drivers were used for brown Citation at San Diego and Los Angles. Figure 34 shows the effect of car, driver and location on a number of statistical parameters based on the VEHC-to-real fuel relationship.

FUEL CONSUMPTION : VEHC vs REAL

Effects of Car, Driver and Location

Car:Silver Driver:1 Loc:SD

Dependent variable is: VECH Cit Fuel
R^2 = 89.2% R^2 (adjusted) = 89.2%
s = 0.0060 with 865 - 2 = 863 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.256066	1	0.256066	7125
Residual	0.031017	863	0.000036	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.010241	0.0005	18.8
Real Fuel (GPM...	1.32463	0.0157	84.4

Car:Silver Driver:1 Loc:LA

Dependent variable is: VECH Cit Fuel
R^2 = 87.3% R^2 (adjusted) = 87.3%
s = 0.0055 with 2982 - 2 = 2980 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.622401	1	0.622401	20500
Residual	0.090476	2980	0.000030	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.008048	0.0003	28.0
Real Fuel (GPM...	1.44763	0.0101	143

All Data for Car:Silver

Dependent variable is: VECH Cit Fuel
R^2 = 87.9% R^2 (adjusted) = 87.9%
s = 0.0057 with 3847 - 2 = 3845 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.901672	1	0.901672	27852
Residual	0.124475	3845	0.000032	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.009121	0.0002	36.5
Real Fuel (GPM...	1.39487	0.0084	167

Car:Brown Driver:2 Loc:SD

Dependent variable is: VECH Cit Fuel
R^2 = 92.7% R^2 (adjusted) = 92.7%
s = 0.0042 with 468 - 2 = 466 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.105616	1	0.105616	5932
Residual	0.008297	466	0.000018	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.012448	0.0005	23.1
Real Fuel (GPM...	1.22657	0.0159	77.0

Car:Brown Driver:3 Loc:LA

Dependent variable is: VECH Cit Fuel
R^2 = 89.9% R^2 (adjusted) = 89.9%
s = 0.0055 with 2063 - 2 = 2061 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.556721	1	0.556721	18299
Residual	0.062703	2061	0.000030	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.006875	0.0003	21.2
Real Fuel (GPM...	1.42176	0.0105	135

All Data for Car:Brown

Dependent variable is: VECH Cit Fuel
R^2 = 90.1% R^2 (adjusted) = 90.1%
s = 0.0054 with 2531 - 2 = 2529 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.664759	1	0.664759	22962
Residual	0.073216	2529	0.000029	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.007969	0.0003	27.8
Real Fuel (GPM...	1.38063	0.0091	152

All Data for Loc:SD

Dependent variable is: VECH Cit Fuel
R^2 = 90.0% R^2 (adjusted) = 90.0%
s = 0.0055 with 1333 - 2 = 1331 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.361760	1	0.361760	12032
Residual	0.040019	1331	0.000030	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.010924	0.0004	27.0
Real Fuel (GPM...	1.29347	0.0118	110

All Data for Loc:LA

Dependent variable is: VECH Cit Fuel
R^2 = 88.2% R^2 (adjusted) = 88.2%
s = 0.0056 with 5045 - 2 = 5043 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	1.17635	1	1.1764	37848
Residual	0.157583	5043	0.000031	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.007839	0.0002	36.2
Real Fuel (GPM...	1.42673	0.0074	194

All Data for Both Cars and Locs

Dependent variable is: VECH Cit Fuel
R^2 = 88.6% R^2 (adjusted) = 88.6%
s = 0.0056 with 6378 - 2 = 6376 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	1.56293	1	1.5629	49472
Residual	0.201430	6376	0.000032	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.008789	0.0002	46.2
Real Fuel	1.38464	0.0062	222

Figure 34

A number of interesting relationships are indicated by Figure 34. The far right column of values shows that the aggregate statistics for each of the Silver and Brown vehicles are very similar, with VEHC-to-real slopes of 1.39 and 1.38 respectively. This indicates that there is not a very large difference in the fuel consumption characteristics between these identical (make and model) vehicles. This conclusion would tend to validate the fact that the data base originally used to produce the VEHC program only used the test results of one vehicle to represent the fuel consumption characteristics of that vehicle's entire class.

Additionally, there appears to be significant differences in the VEHC-to-real slope between different locations and different drivers using the same vehicle. For example, driver 2 for the brown Citation at San Diego had a VEHC-to-real slope of 1.23, while driver 3 with the brown citation at Los Angles had a slope of 1.42. The difference in these slopes indicates that VEHC predicts a different quantity of fuel relative to the actual amount consumed at different locations and for different drivers. The VEHC-to-real fuel ratio should be independent of these parameters.

8.1.3 EFFECTS OF ACCELERATION

A similar type of analysis was done with acceleration* as was done with grade. Acceleration is one of the most important parameters in fuel consumption studies of traffic congestion. A definitive relationship was found in the VEHC-to-real fuel correlation with respect to acceleration. At high acceleration (a link with a total acceleration greater than 80 ft/sec/sec) the slope of this correlation is greater than 2.0. This slope drops consistently at lower accelerations, and eventually approaches 1.0 at accelerations of less than 5 ft/sec/sec. This indicates that the amount VEHC overpredicts fuel consumption ranges considerably between high accelerations and low accelerations.

Because acceleration seems to have such a large effect on the VEHC-to-real Citation fuel curve, this was analyzed in greater detail. These curves were replotted with the limitation that all the link values be at least 15 seconds long. This should have minimized the effects of the 1 to 2 second time lag for fuel consumption of the carburetored Real Citation verses the instantaneous VEHC computer model. Although this dramatically reduced the number of points plotted for the low accelerations, it did not significantly change the above results, as shown in Figures 35 and 36.

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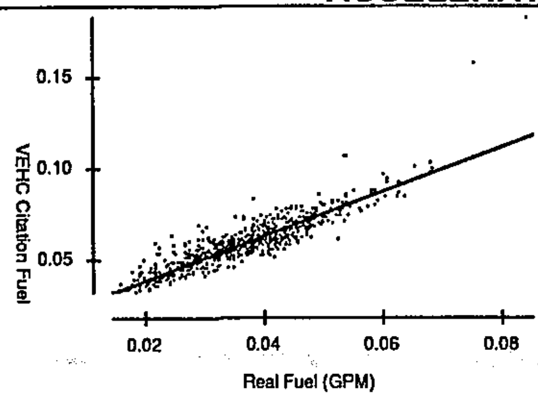
* Acceleration as defined here is the sum total of all the individual positive accelerations experienced while traveling over the link. It is not simply the net difference in speed between the beginning and end of the link. For example, a roadway section that had a velocity profile of 70,72,69,71 ft/sec would have a total positive acceleration of (2+0+2=) 4 ft/sec/sec.

FUEL CONSUMPTION : VEHC vs REAL - HIGH ACCELERATION

ACCELERATION 20 ft/sec^2 to 40 ft/sec^2

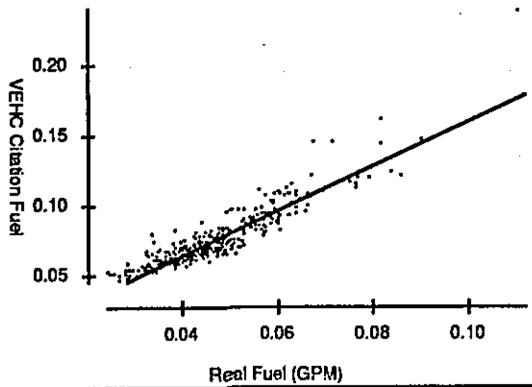


Dependent variable is: **VEHC Citation Fuel**
R^2 = 79.3% R^2 (adjusted) = 79.3%
s = 0.0063 with 708 - 2 = 706 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.106549	1	0.106549	2705
Residual	0.027810	706	0.000039	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.014014	0.0009	15.4
Real Fuel	1.23065	0.0237	52.0

ACCELERATION 40 ft/sec^2 to 80 ft/sec^2

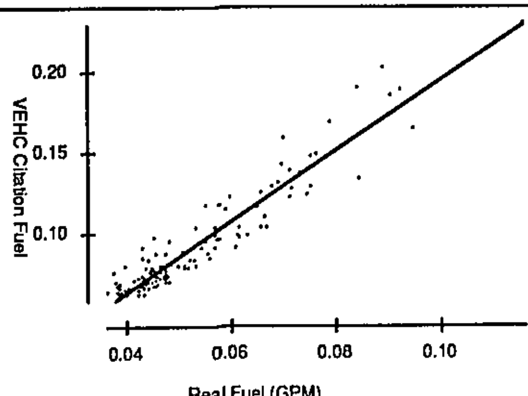


Dependent variable is: **VEHC Citation Fuel**
R^2 = 83.5% R^2 (adjusted) = 83.4%
s = 0.0080 with 375 - 2 = 373 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.121939	1	0.121939	1884
Residual	0.024145	373	0.000065	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.001484	0.0017	0.848
Real Fuel	1.59311	0.0367	43.4

ACCELERATION Greater Than 80 ft/sec^2



Dependent variable is: **VEHC Citation Fuel**
R^2 = 90.8% R^2 (adjusted) = 90.7%
s = 0.0101 with 128 - 2 = 126 degrees of freedom

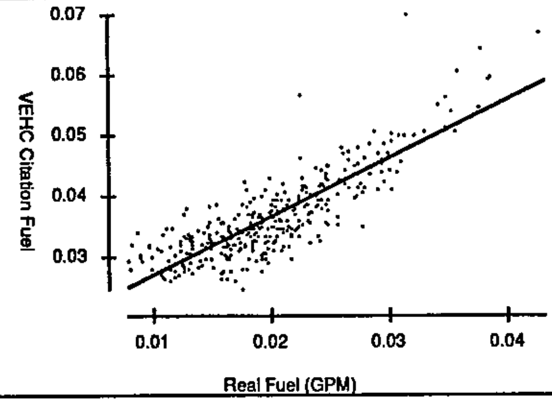
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.128048	1	0.128048	1245
Residual	0.012963	126	0.000103	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	-0.023077	0.0034	-6.79
Real Fuel	2.17916	0.0618	35.3

Figure 35

FUEL CONSUMPTION : VEHC vs REAL - LOW ACCELERATION

ACCELERATION LESS THAN 5 ft/sec^2

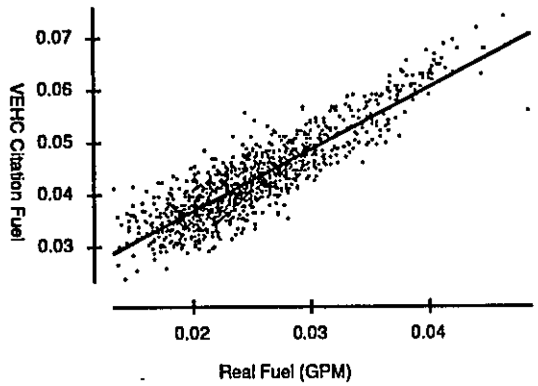


Dependent variable is: **VEHC Citation Fuel**
R^2 = 70.4% R^2 (adjusted) = 70.3%
s = 0.0039 with 344 - 2 = 342 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.012080	1	0.012080	813
Residual	0.005083	342	0.000015	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.017092	0.0007	23.9
Real Fuel	0.972707	0.0341	28.5

ACCELERATION 5 ft/sec^2 to 10 ft/sec^2

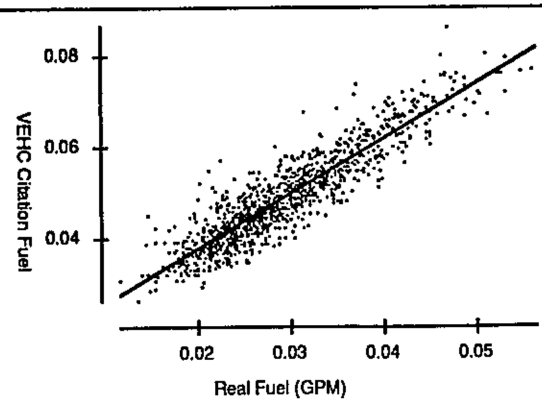


Dependent variable is: **VEHC Citation Fuel**
R^2 = 79.6% R^2 (adjusted) = 79.5%
s = 0.0035 with 1201 - 2 = 1199 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.058708	1	0.058708	4666
Residual	0.015084	1199	0.000013	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.012458	0.0005	27.5
Real Fuel	1.20802	0.0177	68.3

ACCELERATION 10 ft/sec^2 to 20 ft/sec^2



Dependent variable is: **VEHC Citation Fuel**
R^2 = 83.7% R^2 (adjusted) = 83.7%
s = 0.0038 with 1331 - 2 = 1329 degrees of freedom

Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.097303	1	0.097303	6810
Residual	0.018988	1329	0.000014	

Variable	Coefficient	s.e. of Coeff	t-ratio
Constant	0.012938	0.0004	29.7
Real Fuel	1.21990	0.0148	82.5

Figure 36

Finally, a direct statistical analysis was made of the VEHC-to-real fuel consumption ratio when broken down by acceleration ranges. This is shown in Figure 37 below.

Summary Statistics of VEHC/Real Fuel Ratios for Acceleration

							99% Confidence Interval (that True Mean Lies Between These Boundaries)	
Acc. Rng (ft/sec^2)	Number Cases	Mean	Standard Deviation	Variance	Minimum	Maximum	Low Value	High Value
LT 5	344	1.922	0.4397	0.1934	1.260	3.905	1.86	1.98
5 - 10	1201	1.735	0.2055	0.0422	1.161	3.118	1.72	1.75
10 - 20	1331	1.699	0.1897	0.0360	1.301	3.074	1.69	1.71
20 - 40	708	1.644	0.2203	0.0485	1.156	2.740	1.62	1.67
40 - 80	375	1.633	0.1646	0.0271	1.279	2.389	1.61	1.66
GT 80	128	1.722	0.1914	0.0366	1.458	2.272	1.68	1.77

Figure 37

These statistics are based simply on the VEHC-to-real fuel ratios, rather than a least squared linear regression plots as shown in Figures 35 and 36. Although the range of values (in terms of minima to maxima) generally appears to get smaller at higher accelerations, there is no clear trend for the means or standard deviations. The mean of the ratios varies from 1.633 to 1.922 at different accelerations, a range of more than 17%.

Most important are the Z-statistic 99% confidence intervals shown on the far right. Assuming these ratios are normally distributed, the true mean ratio for each acceleration range should be bounded by the high and low values reported above. Because there is no one value of the VEHC-to-real ratio that fits into all these ranges (i.e. the high boundary for the GT 80 is less than the low value for the LT 5), it can be said with 99% confidence that the values for each acceleration range represent a different sample. This is equivalent to saying that: we are greater than 99% confident that the change in VEHC fuel consumption with respect to acceleration for a 1982 Citation is significantly different from the change in measured fuel consumption with acceleration for a 1980 Citation.

Basically, this means that if a roadway segment with two different traffic conditions (which caused two different ranges of aggregate acceleration) were measured to have a 10% gain in fuel consumption with the (real) Citations, VEHC could predict a 27% gain or a 7% loss in fuel consumption. Since many traffic improvements show less than a 10% change in fuel consumption, VEHC would not be adequate to model these improvements.

These conclusions are based entirely on the relationship between the VEHC 1982 fuel injected Citation and our two 1980 carburetored Citations. It is impossible to say if these conclusions are applicable to the other 14 vehicles that VEHC can model. There may be some unknown, but significant, changes in the Citations between 1980 and 1982 that are responsible for the differing fuel consumption vs acceleration characteristics. It seems unlikely that the change in the carburation alone is responsible for this difference.

8.2 FLEET FUEL CONSUMPTION FACTORS

The above analysis indicates that least one specific vehicle's measured fuel consumption cannot be accurately modeled with VEHC. This raises questions as to the applicability of using VEHC to predict generalized fuel consumption factors for different traffic conditions.

However, an assessment of the fuel consumption vs speed relationship was made for both the Real Citations and the VEHC Fleet Vehicle. These are shown in Figures 38 and 39. Figure 39 shows plots of speed vs fuel consumption for the different vehicles at different grade ranges. Because it is difficult to discern so many data points, the mean fuel consumption values for every 5 MPH range (i.e. 5 - 10 MPH, 10 - 20 MPH, etc.) are also plotted with lines segments between them. These average values are tabulated in Figure 38 below.

Summary : Fuel Consumption Rate vs Speed

		Grades GT 1%		Grades 1% to -1%		Grades LT -1%	
Speed Range (MPH)	Average Speed (MPH)	Real Citation (GPM)	VEHC Fleet (GPM)	Real Citation (GPM)	VEHC Fleet (GPM)	Real Citation (GPM)	VEHC Fleet (GPM)
LT 5				0.0970	0.1594	0.1023	0.1636
5-10	7.5	0.0742	0.1278	0.0667	0.1118	0.0637	0.0978
10-15	12.5	0.0613	0.1058	0.0508	0.0878	0.0487	0.0774
15-20	17.5	0.0484	0.0864	0.0437	0.0766	0.0362	0.0638
20-25	22.5	0.0429	0.0776	0.0347	0.0640	0.0347	0.0609
25-30	27.5	0.0409	0.0759	0.0310	0.0591	0.0249	0.0454
30-35	32.5	0.0385	0.0745	0.0335	0.0661	0.0234	0.0476
35-40	37.5	0.0386	0.0790	0.0295	0.0638	0.0234	0.0520
40-45	42.5	0.0356	0.0798	0.0275	0.0643	0.0227	0.0573
45-50	47.5	0.0341	0.0822	0.0247	0.0654	0.0213	0.0596
50-55	52.5	0.0350	0.0880	0.0256	0.0725	0.0199	0.0608
55-60	57.5	0.0363	0.0920	0.0265	0.0765	0.0220	0.0648
GT 60	62.5	0.0358	0.0895	0.0274	0.0770	0.0237	0.0696

Figure 38

Fuel Consumption vs Speed
For Real Citation and VEHC Fleet Vehicles

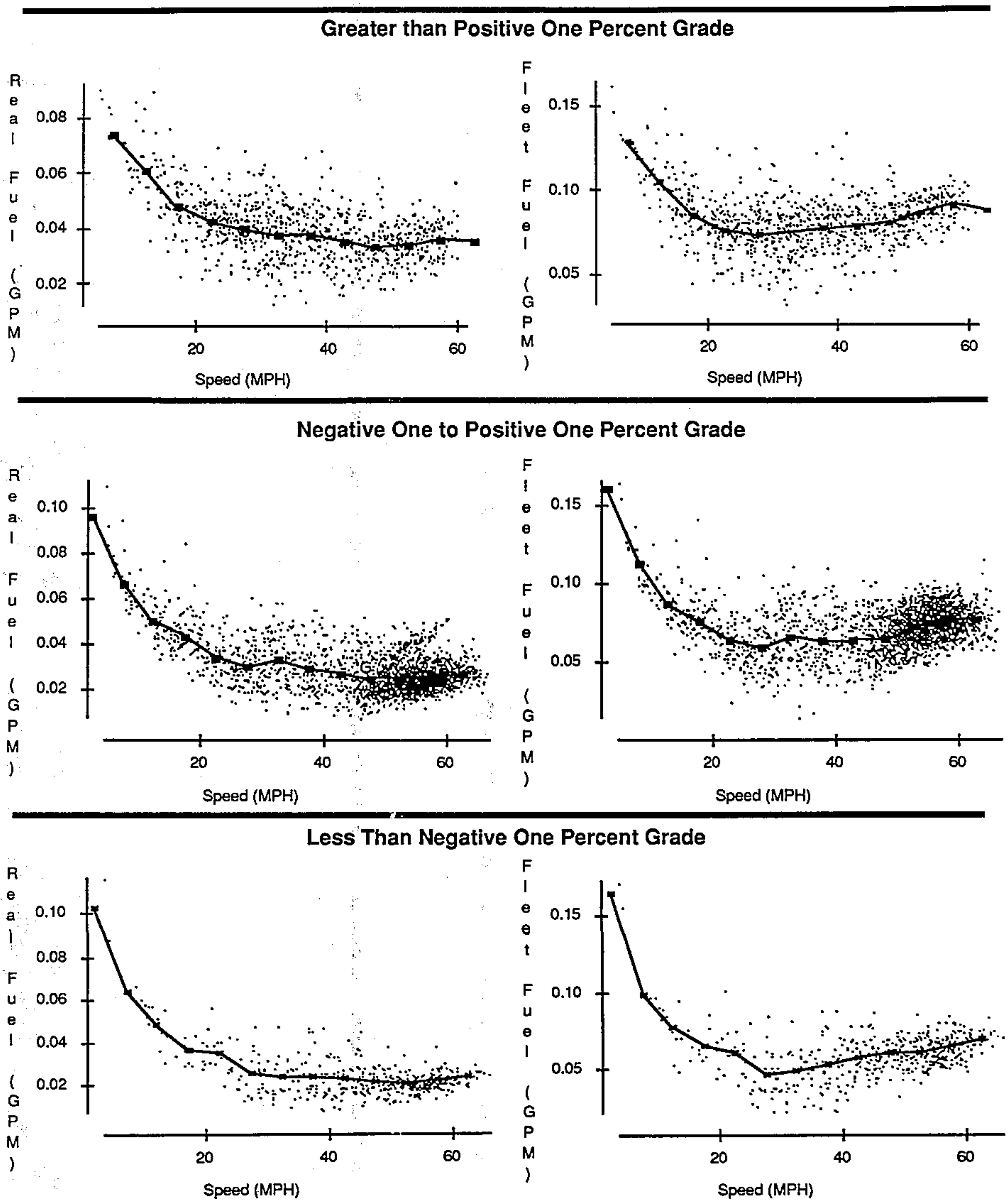


Figure 39

A number of gross trends are apparent in these mean values of the fuel consumption vs speed curves. They all have a high fuel consumption rate at low speeds and then drop significantly at higher speeds. Rather than being a smooth curve, these plots all have a little "notch" in them around 25 - 35 MPH range where the rate of change of slope increases for a while, and then decreases again. The significance of this is unknown.

More significantly, VEHC predicts a minimum fuel consumption rate in the 25 -35 MPH range while the Real Citations got the best fuel economy in the 45 - 55 MPH range. This means that VEHC would show a fuel penalty by increasing the speed on a congested freeway from 30 to 50 MPH, while the Real Citations would actually show a fuel savings This is perhaps the most startling result of this research.

8.3 SUMMARY

This analysis of the link data base indicates that the VEHC Citation does not appear to have the same fuel consumption characteristics as the real Citations, ether in relative or absolute magnitude. More specifically, the ratio of the VEHC Citation to real Citation fuel consumption appears to change with grade, location, driver and (most significantly) acceleration. VEHC does not adequately model our Citation's fuel consumption for these important parameters. This raises questions regarding using the use of the VEHC model for other fuel consumption studies.

Plots of fuel consumption vs speed indicate that the real Citation obtains peak fuel economy at about 50 MPH in congestion, while the VEHC fleet vehicle gets the best fuel economy at about 30 MPH. This indicates that the VEHC model would predict a fuel penalty if the speed on a congested freeway were increased from 30 MPH to 50 MPH, while a fuel savings would be measured with the real Citations.

A much more sophisticated statistical parametric analysis could be performed on this data to determine the effects of traffic volumes, merging length, deceleration, etc. on the VEHC and real Citation fuel consumption. Indeed, such as analysis was performed, but some of the results were problematic due to uncorrected errors in the original data base. The simplified analysis presented above has raised enough questions with regard to the accuracy of the VEHC model that that an extensive reanalysis is probably not warranted at this time.

9. CONCLUSIONS

This project did not meet its original objective of determining fuel consumption factors for a wide variety of driving conditions. It did not statistically validate the fuel consumption model: VEHC, due to the discovery that some of the data in the final data base were invalid after most of the analysis had been completed. If anything, it raised significant questions regarding the applicability of VEHC for congested roadway fuel studies.

However, this project did produce a number of definitive results:

1) The project did produce one of largest data bases of empirically gathered traffic and fuel consumption characteristics available today. This data base has been extensively edited to eliminate errors and flag potential misreadings. Complementary data have also been collected on the VEHC fuel consumption model, which is the basis for the fuel predicting capabilities of such popular traffic models as NETSIM, TRANSIT, and SOAP.

   These data, available on computer discs in both a "raw" and summary format, should prove quite useful in validating existing and future traffic and fuel consumption models.

2) This analysis of the link data base indicates that the VEHC Citation does not appear to have the same fuel consumption characteristics as was measured with the real Citations, ether in relative or absolute magnitude. More specifically, the ratio of the VEHC Citation to real Citation fuel consumption appears to change with grade, location, driver and (most significantly) acceleration. VEHC does not adequately model the Citation's fuel consumption we measured for these important parameters. This raises questions regarding using the use of the VEHC model for other fuel consumption studies.

   Plots of fuel consumption vs speed indicate that the real Citation obtains peak fuel economy at about 50 MPH in congestion, while the VEHC fleet vehicle gets the best fuel economy at about 30 MPH. This indicates that the VEHC model would predict a fuel penalty if the speed on a congested freeway were increased from 30 MPH to 50 MPH, while a fuel savings would actually be measured with the real Citations.

3) A great deal of experience was gained in the various computer techniques necessary to gather and verify traffic data. Numerous algorithms and computer programs were developed for data manipulation. These techniques will prove quite useful as the data manipulation procedures outlined in this report become more commonplace.

4) The Caltrans Congestion Monitoring System was developed as a direct outgrowth of this project. It provides a simplified, completely computerized way for on-the-road data collection and analysis of traffic data. This system is currently being used by all Caltrans Districts, and is available to other states and municipalities.

10. IMPLEMENTATION

The Congestion Monitoring System developed as a direct result of this project has been implemented throughout the California Department of Transportation, and is available to other states and municipalities. It is described in detail in Appendixes B and E.

This system allows traffic engineers to analyze the magnitude, duration and location of traffic congestion on highways and city streets. It is being used to prioritize traffic improvement projects and to determine the effectiveness of Transportation Systems Management (TSM) options. It is being considered for use for sign logging and other inventory studies. This system currently supports seven analysis report formats, with other analysis capabilities currently under development.

This system replaces an ageing mechanical tachograph that was subject to mechanical breakdown. Being entirely electronic, it has reduced data analysis time by more than an order of magnitude. The Caltrans Division of Transportation Operations has projected an annual benefit of over $100,000 due to the system.

This project has confirmed the relationship that fuel consumption decreases with increasing speed on urban freeways up to a speed of 50 MPH for our test vehicles. This relationship had not previously been shown for freeway conditions. It can now definitively be used for environmental and planning studies.

This project also produced a very large coherent data base of 23 separate traffic and fuel consumption parameters in an easy-to-use computer format. This data base can be used by researchers to check and validate other traffic and fuel consumption models, such as NETSIM and TRANSIT.

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APPENDIX A

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
OFFICE OF TRANSPORTATION LABORATORY

April 1984

FUEL EFFICIENT TRAFFIC SIGNAL MANAGEMENT PROGRAM
EVALUATION OF TRANSYT 7F

Submitted to

California Energy Commission

Study Made by	Enviro-Chemical Branch Energy Research and Computer Application Section
Under General Direction of	Mas Hatano, P.E.
Worked Supervised by	Roy Bushey, P.E. Dan Talaga, P.E.
Report by	Dan Talaga, P.E. Joe Palen, P.E.
Technical Analysis by	Que Huynh, P.E. Joe Palen, P.E.

Please call Joe Palen (ATSS 497-2325) if further information on this study is needed.

Mas Hatano

Mas Hatano, Chief
Enviro-Chemical Branch

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EXECUTIVE SUMMARY

The Transportation Laboratory of the California Department of Transportation recently completed an extensive data collection project to evaluate an application of TRANSYT 7F in Redwood City, California. TRANSYT 7F is a computerized traffic simulation model designed to optimize the timings of a traffic signal network. Four measures of effectiveness were used in the evaluation: Total travel time, fuel consumption, delay, and the number of stops. Test data were gathered using a specially equipped research vehicle. The data were analyzed to determine if there was a significant difference in the values obtained for the measures of effectiveness before and after implementation of TRANSYT 7F signal timings.

This study cannot be construed as a blanket evaluation of TRANSYT 7F, but only as an evaluation of this particular application. Although some statistically significant changes were calculated, these changes appeared to be random in nature with no definitive trend of improvement or deterioration.

INTRODUCTION

The Transportation Laboratory (TransLab) of the California Department of Transportation recently completed an extensive data collection project to evaluate an application of TRANSYT 7F in Redwood City, California. TRANSYT 7F is a computerized traffic simulation model designed to optimize a traffic signal network. Data were collected by driving a specially equipped test vehicle over predesigned test routes. The study was conducted under contract to the California Energy Commission (CEC) as part of the Fuel Efficient Traffic Signal Management (FETSIM) grant project.

Redwood City was selected as the test site because of the size and type of its signal network. The selection was made by representatives of the CEC, and the Institute of Transportation Studies (ITS) of the University of California, Berkeley.

For the design of test routes, the Redwood City network broke down into two basic sections. One section was an exterior loop composed of major arterials and the other section was an interior grid network. Test routes were designed to be representative of the entire signalized network. Sampling was done on street sections in proportion to their Average Daily Traffic (ADT). Key intersections were sampled in proportion to turning movement.

DESIGN OF TEST ROUTES

Four test routes were used, two on the exterior arterials and two on the interior grid. The routes were designed to be driven in a sequential pattern so that the terminus of one route was at or very near the beginning of the next

ROUTE 1

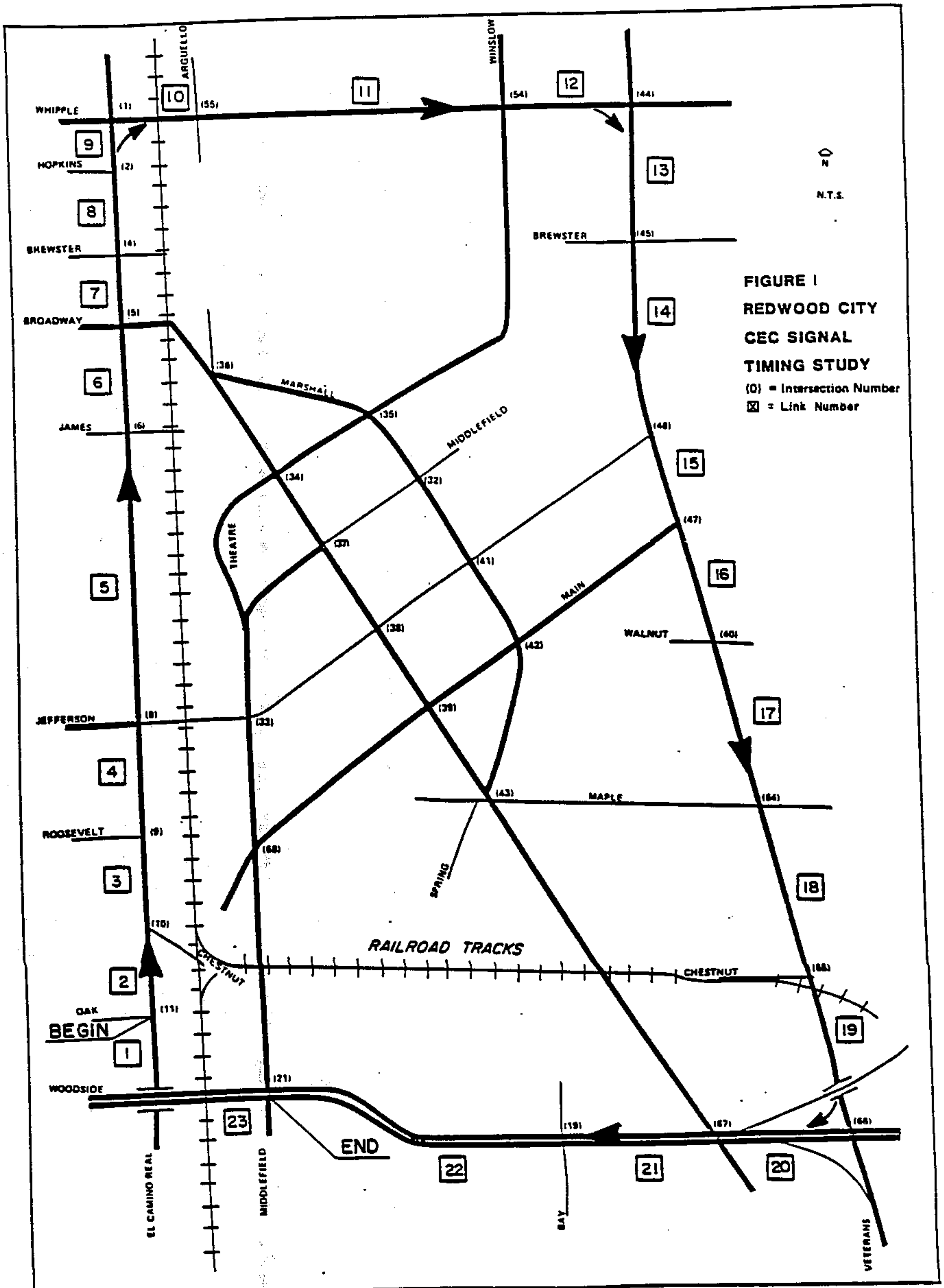


FIGURE 1
REDWOOD CITY
CEC SIGNAL
TIMING STUDY

ROUTE 2

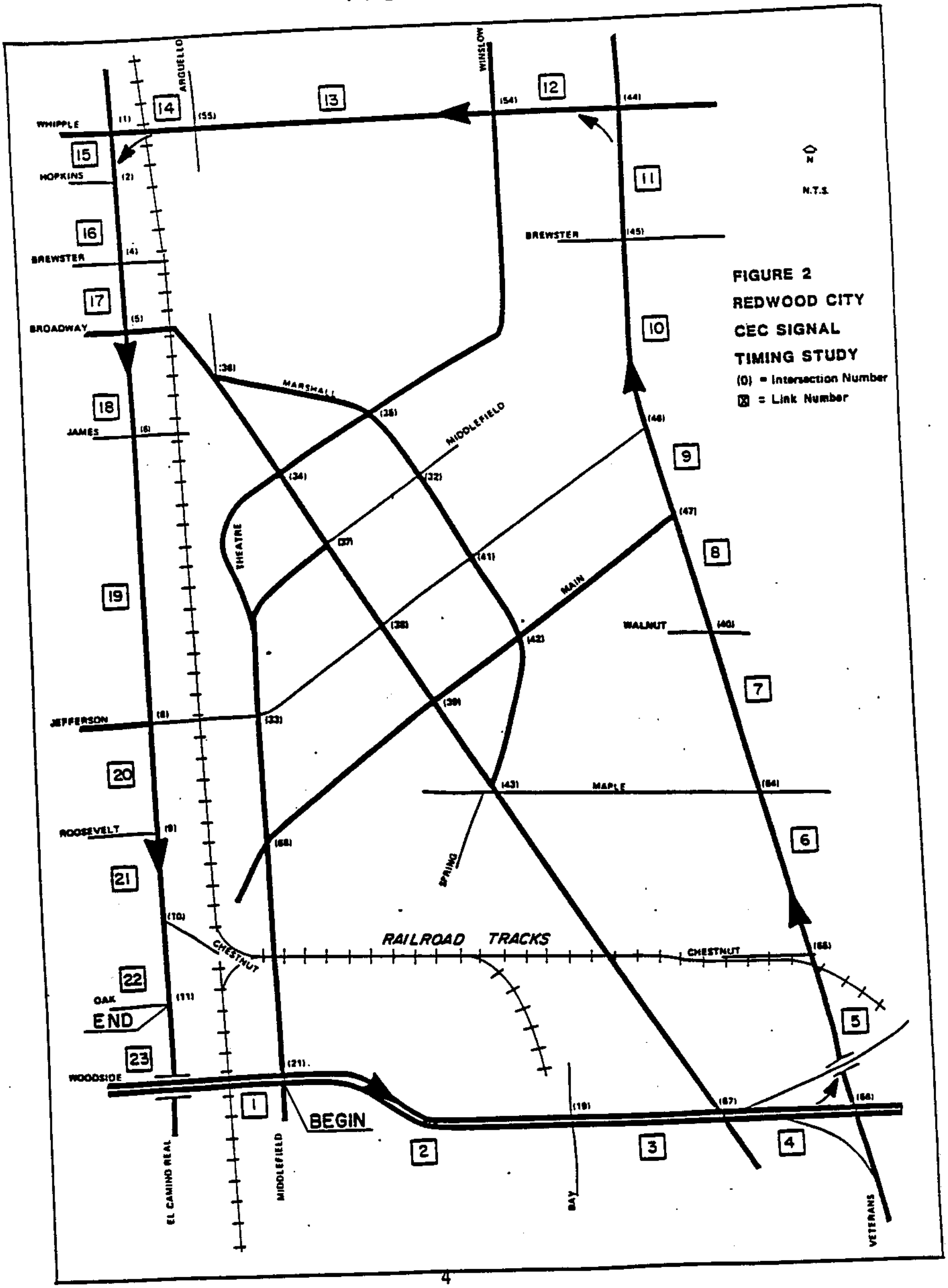


FIGURE 2
REDWOOD CITY
CEC SIGNAL
TIMING STUDY
(0) = Intersection Number
☒ = Link Number

ROUTE 3

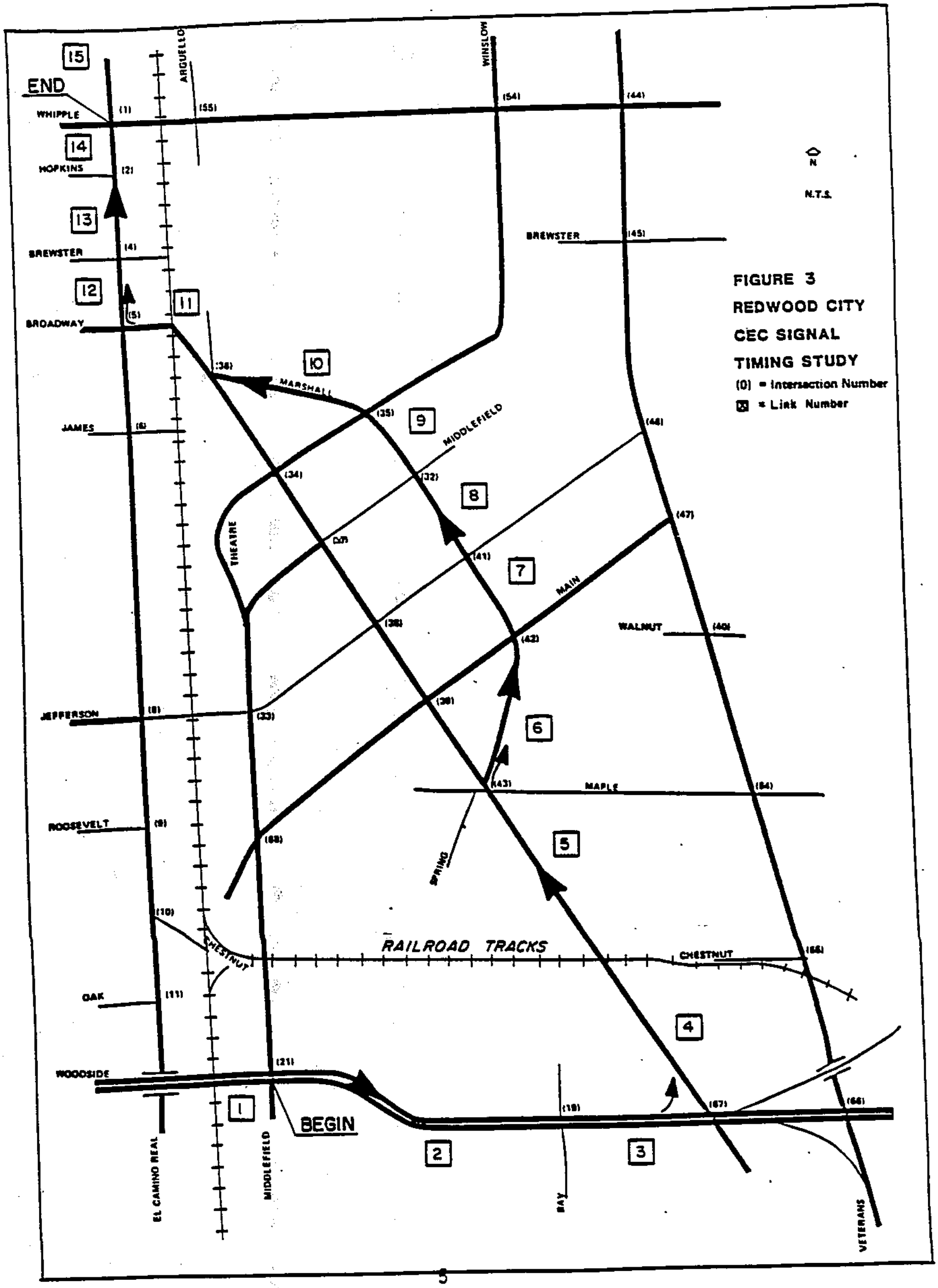
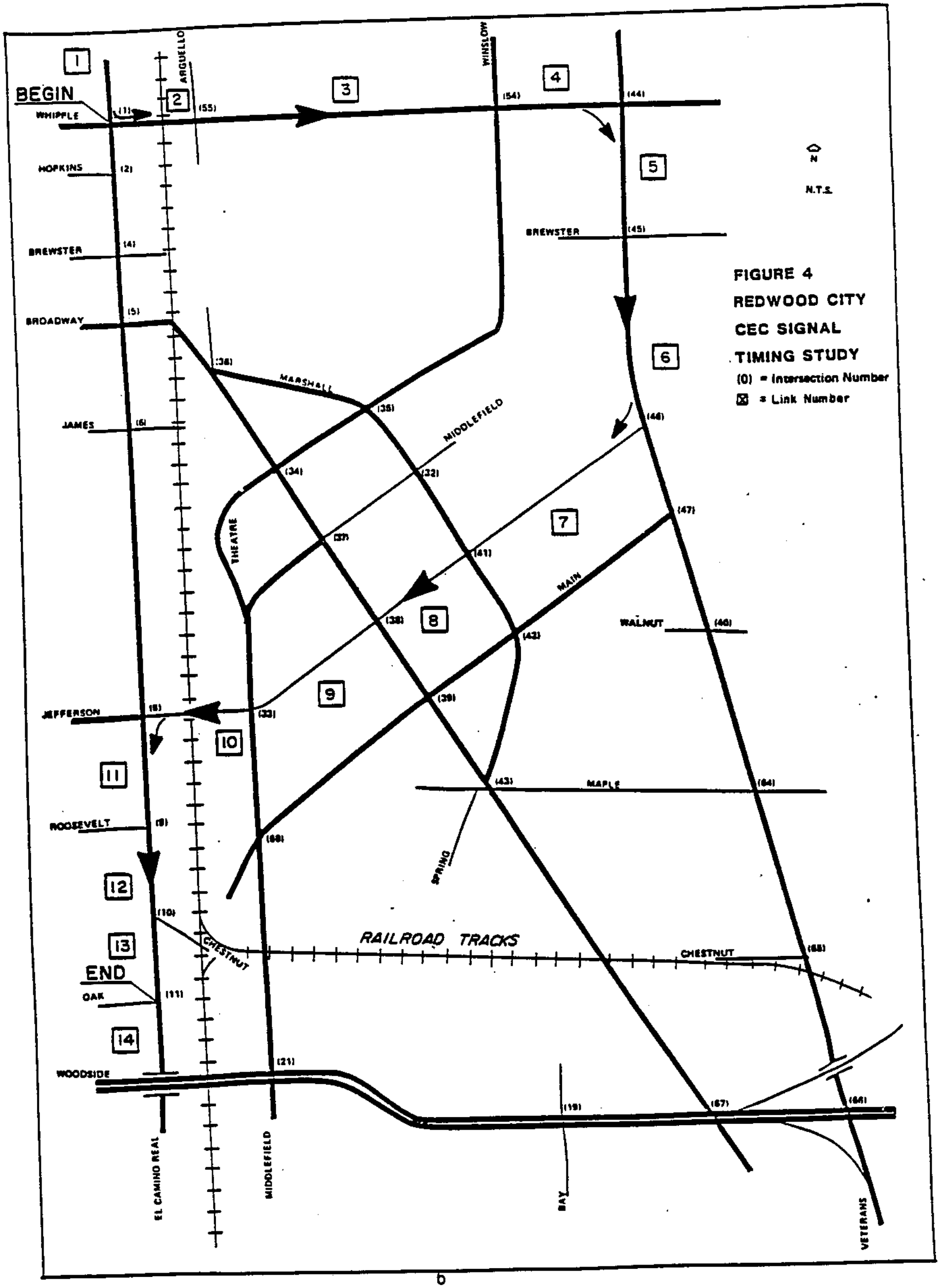


FIGURE 3
REDWOOD CITY
CEC SIGNAL
TIMING STUDY
(0) = Intersection Number
☒ = Link Number
N
N.T.S.
END
BEGIN
WHIPPLE
HOPKINS
BREWSTER
BROADWAY
JAMES
JEFFERSON
ROOSEVELT
OAK
WOODSIDE
ARGUELLO
WINSLOW
MARSHALL
MIDDLEFIELD
THEATRE
MAIN
WALNUT
MAPLE
SPRING
RAILROAD TRACKS
CHESTNUT
EL CAMINO REAL
BAY
VETERANS

ROUTE 4



BEGIN
END
WHIPPLE
HOPKINS
BREWSTER
BROADWAY
JAMES
JEFFERSON
ROOSEVELT
OAK
WOODSIDE
ARGUELLO
WINSLOW
MARSHALL
MIDDLEFIELD
THEATRE
MAIN
WALNUT
MAPLE
SPRING
CHESTNUT
RAILROAD TRACKS
EL CAMINO REAL
BAY
VETERANS
N
N.T.S.
FIGURE 4
REDWOOD CITY
CEC SIGNAL
TIMING STUDY
(0) = Intersection Number
☒ = Link Number

route. The four test routes are shown in Figures 1 through 4. Each of the four different routes was tested in each of four different time periods. The time periods studied were: a.m. peak 7:00 to 9:00, midday peak 11:00 to 1:00, p.m. off-peak 1:30 to 3:30, and p.m. peak 4:00 to 6:00. To prevent any particular route from being sampled at a consistent time, the two-hour periods were further divided into 15 minute time segments. An attempt was made to evenly distribute the routes starting times within these 15 minute segments.

DATA COLLECTION

The testing was conducted using a specially equipped 1980 Chevrolet Citation. The vehicle was equipped with fuel metering as well as distance and time measuring devices. Fuel consumption was measured to 0.1 cc per second with an uncertainty of 0.5 percent of the instantaneous flow rate. Distance was measured to an accuracy of within three feet per mile. Time, fuel consumption, and distance information were automatically recorded on cassette tapes. The tapes were later processed on an Apple II computer. The recording device, equipped with a series of push buttons, allowed for the recording of special events. For this analysis, one push button was used to indicate each significant intersection or link node. Another push button, indicated on the printouts as Event "1", was used to indicate each time a red light was experienced. Event "2" marked a crossing train. The analysis program used by the Apple II automatically printed out the total time the vehicle was traveling at less than five miles per hour as delay. The number of stops, and any special events were also printed out. Four measures of effectiveness (MOE's) were used in the evaluation: total travel time, fuel consumption, delay, and the number of stops. These could easily be determined from the recorded information. A complete copy of the field notes and computer run summaries are attached as Appendix A.

Data were gathered in a study of the existing signal timings in September and October of 1983. It was expected that the new timing plan generated by TRANSYT 7F would be implemented in October, and after a short period to allow traffic to adjust, the after study would be conducted. Due to difficulties between the city and its consultant, the new timing plan was not initiated until February 1984. Because of the excessive time lag between studies, a second existing signal timing study was conducted in January 1984. The TRANSYT 7F optimized study was conducted in February.

Two data collection teams were used during the field investigations. A team consisted of a driver and a monitor. Each team collected data for two time periods. The driver and monitor alternated assignments for the different periods, but the same person always drove for a specific time period. All four routes were sampled in each of the time periods.

ANALYSIS OF DATA

For the analysis of the field data, the first and last link values were subtracted from the run totals. This was done to insure the values obtained were for consistent length routes. The randomness of where the instrument was started and stopped is thereby reduced.

In accordance with analysis guidelines and requirements prescribed by ITS, the modified run totals for each MOE were analyzed to determine their mean and standard deviation. Summary tables of the existing and TRANSYT 7F optimized MOE statistics are included as Tables 1 through 4. A student T-test was used to determine the level of confidence of the results. Forms provided by the CEC were used to present the findings. These analyses of field evaluation results are included in pages 17 through 32.

It was expected that some minor adjustments would be needed to optimize traffic flow. It was noted that severe traffic congestion occurred at specific intersections after implementation of the TRANSYT 7F signal timings. TransLab engineers reported these findings to the Redwood City Traffic Department. These timings were changed and congestion reduced. Accordingly, traffic MOE data for intersections where it was known that the signal timings were changed, were deleted from the statistical analysis. It is possible that the timings of some intersections could have been altered without TransLab engineers' knowledge.

CONCLUSIONS

A comparison of the statistical values obtained from the analysis of the field data of the before and after studies indicated a random distribution of improvement and disbenefit to fuel consumption, an increase to both travel time and delay, and a decrease in the number of stops. No correlation could be shown between fuel consumption and the other three independent MOE's. The magnitude of the improvement or deterioration was unrelated to route, time of day, or driver. For ease of comparison, the percent change of each of the four MOE's was plotted in Figures 5 through 8.

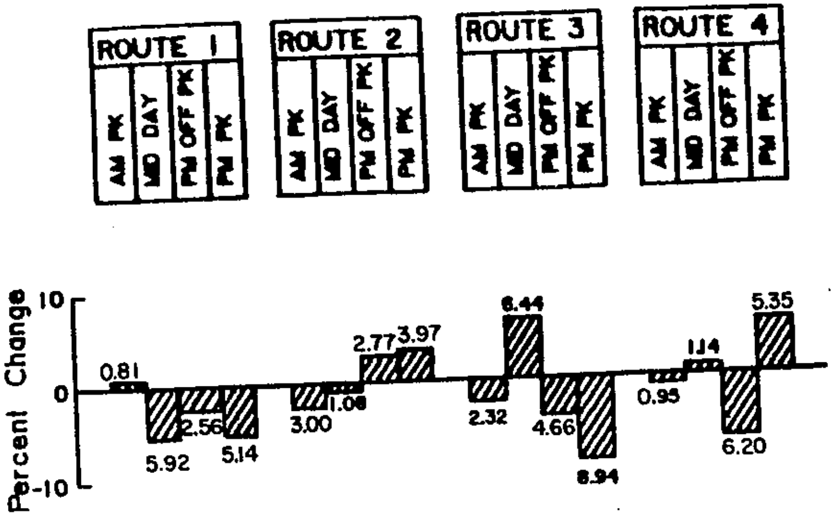


Fig. 5. PERCENT CHANGE OF FUEL CONSUMPTION

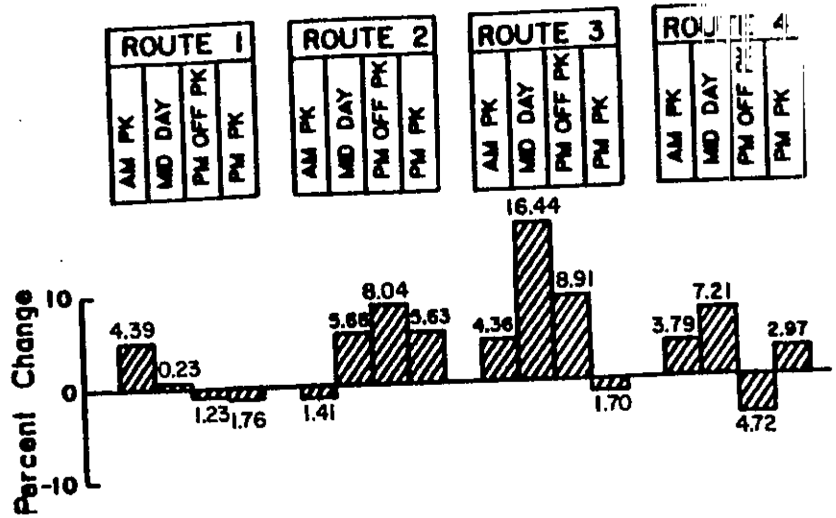


Fig. 6. PERCENT CHANGE OF TRAVEL TIME

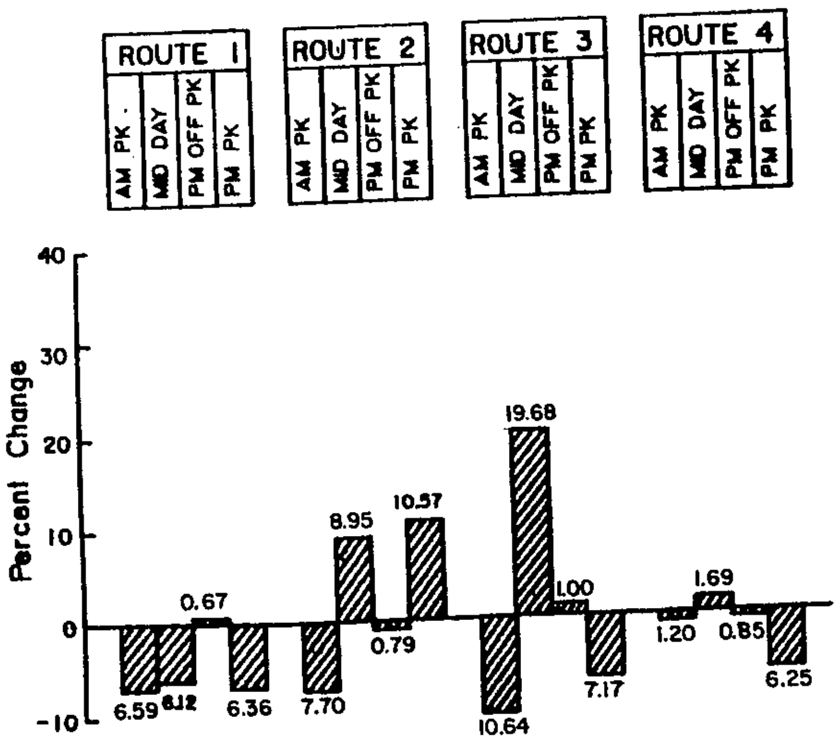


Fig. 7. PERCENT CHANGE OF NUMBER OF STOPS

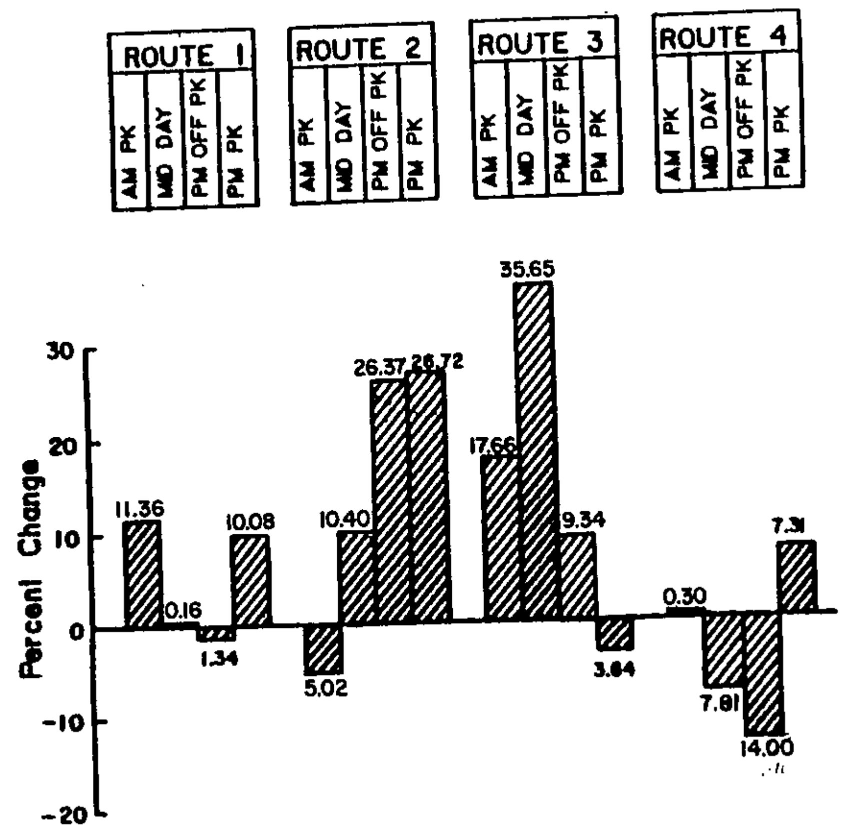


Fig. 8. PERCENT CHANGE OF DELAY TIME

The intention of TRANSYT 7F is to reduce delay in the traffic network by allowing for the steady progression of platoons of vehicles through consecutive intersections. No such steady progression of vehicle platoons was observed in the field. Consecutive intersection signal timings appeared to lack coordination.

This study cannot be construed as a blanket evaluation of TRANSYT 7F, but only as an evaluation of this particular application.

DISCUSSION

The lack of a definitive trend in the MOE's may be attributed to any of at least three possibilities: 1) the TRANSYT 7F computer program was not input correctly, 2) the signal timings output by TRANSYT 7F were not implemented properly, or 3) the TRANSYT 7F program cannot effectively model the actuated and complicated type of traffic network present in Redwood City. These three items are discussed as follows:

1) The TRANSYT program not input correctly

TransLab engineers were not involved in the preparation or modeling of TRANSYT 7F for Redwood City. Therefore, no comments are made concerning the validity of the modeling.

2) TRANSYT 7F not implemented correctly

TransLab engineers were not involved in the implementation of the timing signal but expect that it was properly performed. As stated earlier, when severe problems were noted in the TRANSYT 7F optimized timings they were reported and the timings changed. TransLab field engineers indicated that some intersection signal timings appeared to change within the time frame of the optimized study. If such changes were made to enhance the system or for whatever reason, this would indicate the analysis was not conducted using a consistent data base.

3) <u>The TRANSYT 7F program cannot model the type of traffic network presented in Redwood City</u>

It should be noted that the Redwood City network contains several railroad crossings. Each of the four test routes contained at least one railroad crossing. These crossings are given first priority by adjacent intersection signals. Whenever a train is present, links which intersect the crossings are denied green time. In the extreme case, this can cause delay for two or three cycle lengths. TRANSYT 7F may not adequately handle this situation, as the interruption by a train is a random occurrence within the signal timing sequence. The occurrence of these events was recorded in the data and identification can be made where delay was influenced by a train crossing. These events were viewed as random events; as likely to have occurred during study of the existing conditions as to have occurred during study of the optimized condition. For this reason, no attempt was made to remove the effects of the train crossing from the overall data.

A more disaggregate analysis of specific links might yield information on localized improvements for some MOE's. TRANSYT 7F, however, is supposed to improve the entire traffic network, rather than individual subsystems.

TABLE 1

Measures of Effectiveness
Statistical Summary
AM Peak Period

		TIME			FUEL			STOPS			DELAY		
		N.O.R.	MEAN	STD. DV.	N.O.R	MEAN	STD. DV	N.O.R	MEAN	STD. DV.	N.O.R	MEAN	STD. DV
RTE 1	BEFORE	23	619^{87}	70^{89}	15	649^{87}	62^{86}	19	8^{37}	2^{11}	19	173^{21}	51^{33}
	AFTER	30	650^{43}	66^{78}	30	655^{13}	61^{45}	30	7^{80}	1^{97}	30	193^{27}	52^{45}
	CHANGE		+4.90%			+0.81%			-6.8%			+11.58%	
RTE 2	BEFORE	22	735^{18}	95^{97}	15	731^{20}	59^{68}	17	9^{82}	2^{07}	17	284^{88}	83^{90}
	AFTER	30	724^{70}	85^{85}	30	712^{57}	52^{57}	30	9^{10}	1^{58}	30	269^{02}	68^{79}
	CHANGE		-1.43%			-2.56%			-7.33%			-5.56%	
RTE 3	BEFORE	21	440^{43}	41^{82}	13	433^{0}	37^{73}	17	7^{12}	1^{69}	17	144^{18}	38^{26}
	AFTER	25	459^{64}	75^{00}	25	432^{72}	60^{92}	25	6^{36}	1^{60}	25	169^{64}	56^{60}
	CHANGE		+4.36%			-2.32%			-10.67%			-17.66%	
RTE 4	BEFORE	24	430^{54}	70^{22}	14	431^{93}	45^{16}	18	5^{78}	1^{40}	18	164^{0}	67^{54}
	AFTER	25	446^{88}	61^{57}	25	427^{84}	55^{60}	24	5^{71}	1^{23}	24	164^{50}	59^{03}
	CHANGE		+3.80%			-0.95%			-1.21%			+0.30%	

TABLE 2

Measures of Effectiveness
Statistical Summary
Midday Peak Period

		TIME			FUEL			STOPS			DELAY		
		N.O.R.	MEAN	STD. DV.	N.O.R.	MEAN	STD. DV	N.O.R.	MEAN	STD. DV.	N.O.R.	MEAN	STD. DV
RTE 1	BEFORE	23	759^{22}	122^{58}	13	715^{62}	63^{38}	20	9^{80}	2^{40}	21	280^{33}	118^{46}
	AFTER	25	776^{56}	87^{18}	25	673^{72}	60^{86}	25	9^{20}	2^{31}	25	269^{68}	77^{54}
	CHANGE		+2.28%			-5.68%			-6.12%			-3.80%	
RTE 2	BEFORE	24	809^{71}	66^{71}	14	752^{0}	43^{23}	22	10^{59}	1^{50}	22	308^{86}	66^{56}
	AFTER	26	855^{50}	105^{46}	26	743^{88}	66^{05}	26	11^{54}	2^{52}	26	338^{46}	87^{59}
	CHANGE		+5.66%			-1.08%			+8.97%			+9.58%	
RTE 3	BEFORE	24	470^{0}	66^{20}	14	437^{71}	33^{39}	22	5^{59}	1^{68}	22	165^{64}	60^{12}
	AFTER	18	547^{33}	76^{79}	18	465^{89}	45^{62}	18	7^{83}	1^{72}	18	224^{39}	75^{20}
	CHANGE		+16.45%			+6.44%			+40.07%			+35.47%	
RTE 4	BEFORE	33	514^{91}	80^{99}	12	435^{08}	57^{94}	21	7^{05}	1^{36}	21	223^{38}	71^{70}
	AFTER	18	517^{56}	35^{32}	18	440^{06}	26^{27}	18	7^{17}	1^{04}	18	205^{94}	34^{44}
	CHANGE		+0.51%			+1.14%			+1.70%			+7.80%	

TABLE 3

Measures of Effectiveness
Statistical Summary
PM Off Peak Period

		TIME			FUEL			STOPS			DELAY		
		N.O.R	MEAN	STD.DV.	N.O.R	MEAN	STD.DV	N.O.R	MEAN	STD.DV.	N.O.R	MEAN	STD.DV
RTE 1	BEFORE	21	787^{86}	102^{59}	12	644^{72}	53^{81}	19	9^{63}	2^{39}	19	263^{32}	93^{50}
	AFTER	23	779^{04}	88^{96}	23	681^{61}	60^{27}	23	9^{70}	2^{05}	23	259^{78}	79^{12}
	CHANGE		-1.12%			+2.59%			+0.73%			-1.34%	
RTE 2	BEFORE	22	851^{50}	94^{76}	11	750^{56}	32^{93}	20	11^{37}	1^{95}	19	315^{68}	83^{99}
	AFTER	23	920^{91}	176^{52}	23	772^{30}	94^{79}	23	11^{26}	1^{68}	23	403^{87}	177^{84}
	CHANGE		+8.15%			+2.90%			-0.97%			+27.94%	
RTE 3	BEFORE	23	524^{73}	114^{64}	12	476^{63}	39^{40}	22	7^{68}	2^{06}	22	207^{95}	71^{14}
	AFTER	16	537^{31}	64^{77}	16	453^{75}	45^{76}	16	7^{44}	1^{50}	16	208^{00}	63^{69}
	CHANGE		+2.40%			-4.00%			-3.13%			+0.02%	
RTE 4	BEFORE	23	543^{55}	59^{97}	13	463^{78}	45^{05}	22	6^{44}	2^{12}	22	257^{46}	85^{79}
	AFTER	16	520^{88}	65^{61}	16	434^{75}	47^{93}	16	6^{63}	1^{45}	16	211^{44}	63^{73}
	CHANGE		-4.17%			-6.27%			-4.47%			-17.87%	

TABLE 4

Measures of Effectiveness
Statistical Summary
PM Peak Period

		TIME			FUEL			STOPS			DELAY		
		N.O.R.	MEAN	STD.DV.	N.O.R.	MEAN	STD.DV	N.O.R.	MEAN	STD.DV.	N.O.R.	MEAN	STD.DV
RTE 1	BEFORE	24	816^{46}	145^{59}	14	709^{21}	86^{88}	20	10^{05}	2^{82}	20	279^{75}	129^{83}
	AFTER	22	883^{55}	93^{55}	22	671^{41}	50^{74}	22	9^{36}	1^{73}	22	302^{45}	86^{63}
	CHANGE		-1.58%			-5.33%			-6.87%			+8.11%	
RTE 2	BEFORE	21	806^{29}	98^{45}	13	688^{54}	53^{42}	17	9^{65}	1^{73}	15	268^{80}	74^{77}
	AFTER	21	851^{67}	100^{75}	21	715^{86}	53^{66}	21	10^{67}	1^{28}	21	340^{62}	89^{21}
	CHANGE		+5.63%			+3.97%			+10.57%			+26.72%	
RTE 3	BEFORE	20	566^{20}	75^{04}	15	465^{20}	97^{73}	17	7^{35}	1^{77}	17	238^{65}	71^{73}
	AFTER	23	550^{52}	61^{86}	23	423^{61}	33^{00}	23	6^{83}	1^{03}	23	229^{96}	56^{43}
	CHANGE		-2.77%			-8.94%			-7.07%			-3.64%	
RTE 4	BEFORE	21	531^{81}	86^{78}	12	408^{33}	57^{14}	18	6^{67}	1^{78}	18	228^{61}	60^{32}
	AFTER	24	547^{63}	120^{29}	24	432^{50}	63^{96}	24	6^{25}	1^{87}	24	245^{33}	106^{53}
	CHANGE		+2.97%			+5.92%			-6.3%			+7.31%	

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 7:00 → 9:00 (AM)
ROUTE 1 ; 3.52 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (SEC ~~MIN.~~ / MILE)	DELAY (SEC ~~MIN.~~ / MILE)	STOPS (NO. / MILE)	FUEL (ML ~~GAL.~~ / MILE)
BEFORE	MEAN, X_B	176.10 (N_B=23)	49.21 (N_B=19)	2.38 (N_B=19)	184.61 (N_B=15)
	STD. DEV., S_B	20.14	14.58	0.60	17.86
AFTER	MEAN, X_A	184.78 (N_A=30)	54.91 (N_A=30)	2.22 (N_A=30)	186.12 (N_A=30)
	STD. DEV., S_A	18.97	14.90	0.56	17.46
STATISTICAL SIGNIFICANCE TEST	CHANGE, $\lvert X_B - X_A \rvert$	8.68	5.70	0.16	1.51
	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	5,44	4,31	0.17	5.61
	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	1.59 (D_f=48)	1.32 (D_f=41)	0.93 (D_f=38)	0.27 (D_f=29)
	CONFIDENCE LEVEL (1 - X in %)	93%	90%	81%	60%

N_B = NUMBER OF BEFORE - STUDY TEST RUNS
N_A = " " AFTER - STUDY " "
D_f = DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY [illegible] CONTROL PERIOD 1100 → 1300 (MI)

ROUTE 1 ; [illegible]

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC / MILE)	DELAY (~~MIN.~~ SEC / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	215^{69} ($N_B = 33$)	79^{69} ($N_B = 21$)	2^{78} ($N_B = 20$)	203^{30} ($N_B = 13$)
	STD. DEV., S_B	34^{82}	33^{65}	$6.^{63}$	18^{01}
AFTER	MEAN, X_A	220^{61} ($N_A = 25$)	76^{61} ($N_A = 25$)	$2.^{61}$ ($N_A = 25$)	191^{40} ($N_A = 25$)
	STD. DEV., S_A	24^{77}	22^{03}	$0^{.66}$	17^{29}
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	4^{92}	3^{03}	0^{17}	11^{90}
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	8^{79}	8^{56}	0^{19}	$6.^{08}$
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	0^{56} ($D_f = 41$)	$0.^{35}$ ($D_f = 35$)	$0.^{90}$ ($D_f = 44$)	1^{96} ($D_f = 25$)
	CONFIDENCE LEVEL (1 - X in %)	73%	64%	80%	97%

N_B : NUMBER OF BEFORE - STUDY TEST RUNS.

N_A : " " AFTER - STUDY TEST RUNS

D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 13:30 - 15:30 (M2)

ROUTE 1 ; 3.52 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC / MILE)	DELAY (~~MIN.~~ SEC / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	223.82 (N_B = 21)	74.81 (N_B = 19)	2.74 (N_B = 19)	198.78 (N_B = [illegible])
	STD. DEV., S_B	29.14	26.56	0.68	15.29
AFTER	MEAN, X_A	221.32 (N_A = 23)	73.80 (N_A = 23)	2.76 (N_A = 23)	193.63 (N_A = 23)
	STD. DEV., S_A	25.27	22.48	0.58	17.12
STATISTICAL SIGNIFICANCE TEST	CHANGE, $\lvert X_B - X_A \rvert$	2.50	1.01	0.01	.5.15
	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	8.26	7.69	0.20	5.68
	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	0.30 (D_f = 42)	.0.13 (D_f = 37)	0.10 (D_f = 37)	0.91 (D_f = 27)
	CONFIDENCE LEVEL (1 - X in %)	< 60%	< 60%	< 60%	80%

N_B = NUMBER OF BEFORE-STUDY TEST RUNS

N_A = " " AFTER-STUDY " "

D_f = DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City. CONTROL PERIOD ~~1600~~ 1600/1800 (PM)
ROUTE 1; 3.52 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC / MILE)	DELAY (~~MIN.~~ SEC / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	$231^{\underline{95}}$ ($N_B = 24$)	$79^{\underline{47}}$ ($N_B = 20$)	$2.^{\underline{86}}$ ($N_B = 20$)	$201^{\underline{48}}$ ($N_B = 14$)
	STD. DEV., S_B	$41^{\underline{36}}$	$36^{\underline{88}}$	$0^{\underline{80}}$	$24.^{\underline{68}}$
AFTER	MEAN, X_A	$228^{\underline{28}}$ ($N_A = 22$)	$85^{\underline{92}}$ ($N_A = 22$)	$2.^{\underline{66}}$ ($N_A = 22$)	$190^{\underline{74}}$ ($N_A = 22$)
	STD. DEV., S_A	$26^{\underline{58}}$	$24^{\underline{61}}$	$0.^{\underline{49}}$	$14^{\underline{41}}$
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	$3^{\underline{67}}$	$6^{\underline{45}}$	$0^{\underline{20}}$	$10^{\underline{74}}$
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	$10^{\underline{17}}$	$9^{\underline{78}}$	$0^{\underline{21}}$	$7^{\underline{28}}$
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	$0.^{\underline{36}}$ ($D_f = 41$)	$0^{\underline{66}}$ ($D_f = 34$)	$0^{\underline{97}}$ ($D_f = 32$)	$1^{\underline{48}}$ ($D_f = 20$)
	CONFIDENCE LEVEL (1 - X in %)	64%	74%	82%	92%

N_B : NUMBER OF BEFORE-STUDY TEST RUNS
N_A : " " AFTER " " "
D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 07:00 - 09:00 (AM)

ROUTE 2 ; 3.55 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME ($\frac{\text{~~MIN.~~ SEC.}}{\text{MILE}}$)	DELAY ($\frac{\text{~~MIN.~~ SEC.}}{\text{MILE}}$)	STOPS ($\frac{\text{NO.}}{\text{MILE}}$)	FUEL ($\frac{\text{~~GAL.~~ ML.}}{\text{MILE}}$)
BEFORE	MEAN, X_B	207.09 (N_B = 22)	80.23 (N_B = 17)	2.59 (N_B = 17)	205.97 (N_B = 15)
	STD. DEV., S_B	27.03	23.63	0.58	16.81
AFTER	MEAN, X_A	204.14 (N_A = 30)	75.79 (N_A = 30)	2.56 (N_A = 30)	200.72 (N_A = 30)
	STD. DEV., S_A	24.18	19.38	0.45	14.81
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	2.95	4.44	0.03	5.25
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	7.26	6.79	0.16	5.11
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	0.41 (D_f = 44)	0.66 (D_f = 30)	0.18 (D_f = 28)	1.03 (D_f = 27)
	CONFIDENCE LEVEL (1 - X in %)	65%	74%	< 60%	83%

N_B : NUMBER OF BEFORE - STUDY TEST RUNS

N_A : " " AFTER - STUDY " "

D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 1100 → 1300 (ML)
ROUTE 2, 3.55 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC. / MILE)	DELAY (~~MIN.~~ SEC / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	228.09 (N_B=24)	86.36 (N_B=22)	2.98 (N_B=22)	211.83 (N_B=14)
	STD. DEV., S_B	18.79	18.50	0.42	12.18
AFTER	MEAN, X_A	240.99 (N_A=26)	95.34 (N_A=26)	3.25 (N_A=26)	209.54 (N_A=26)
	STD. DEV., S_A	29.71	24.67	0.71	18.61
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	12.90	8.98	0.27	2.29
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	6.98	6.24	0.17	4.89
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	1.85 (D_f=44)	1.44 (D_f=47)	1.63 (D_f=43)	0.17 (D_f=31)
	CONFIDENCE LEVEL (1 - X in %)	96%	90%	95%	68%

N_B : NUMER OF ~~BEFORE~~ BEFORE-STUDY TEST RUNS
N_A : " " AFTER " " "
D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 13:30 – 15:30 (M2)

ROUTE 2 ; 3.55 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (SEC ~~MIN.~~ / MILE)	DELAY (SEC. MIN. / MILE)	STOPS (NO. / MILE)	FUEL (ML. GAL. / MILE)
BEFORE	MEAN, X_B	239.86 (N_B = 22)	88.92 (N_B = 19)	3.20 (N_B = 20)	211.43 (N_B = 11)
	STD. DEV., S_B	26.69	23.66	0.55	9.28
AFTER	MEAN, X_A	259.41 (N_A = 23)	113.77 (N_A = 23)	3.17 (N_A = 23)	217.55 (N_A = 23)
	STD. DEV., S_A	49.72	50.11	0.47	26.70
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	19.55	24.85	0.03	6.12
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	11.83	11.77	0.16	6.23
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	1.65 (D_f = 35)	2.11 (D_f = 34)	0.19 (D_f = 40)	0.98 (D_f = 31)
	CONFIDENCE LEVEL (1 - X in %)	94%	97%	< 60%	82%

N_B : NUMBER OF BEFORE - STUDY TEST RUNS

N_A : " " AFTER - STUDY " "

D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 1600 – 1800 (PM)
ROUTE 2 ; 3.55 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC. / MILE)	DELAY (~~MIN.~~ SEC. / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	227^{12} ($N_B = 21$)	75^{72} ($N_B = 15$)	2^{72} ($N_B = 17$)	193^{95} ($N_B = 13$)
	STD. DEV., S_B	27^{73}	21^{06}	0^{49}	15^{05}
AFTER	MEAN, X_A	239^{91} ($N_A = 21$)	95^{95} ($N_A = 21$)	$3.^{01}$ ($N_A = 21$)	201^{65} ($N_A = 21$)
	STD. DEV., S_A	28^{38}	25^{13}	$0.^{36}$	15^{12}
STATISTICAL SIGNIFICANCE TEST	CHANGE, $\lvert X_B - X_A \rvert$	12^{79}	20^{23}	0^{29}	7^{70}
	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	8^{66}	7^{72}	0^{14}	5^{32}
	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	$1.^{48}$ ($D_f = 42$)	2^{62} ($D_f = 35$)	$2.^{04}$ ($D_f = 30$)	$1.^{45}$ ($D_f = 28$)
	CONFIDENCE LEVEL (1 – X in %)	92%	99%	97%	92%

N_B : NUMBER OF BEFORE-STUDY TEST RUNS
N_A : ″ ″ AFTER ″ ″ ″
D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 0700 → 0900 (AM)
ROUTE 3 ; 2.08 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's): TRAVEL TIME (~~MIN.~~ SEC / MILE)	DELAY (~~MIN.~~ SEC / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	211.75 (N_B = 21)	69.32 (N_B = 17)	3.42 (N_B = 17)	212.98 (N_B = 13)
	STD. DEV., S_B	20.11	18.39	0.81	17.97
AFTER	MEAN, X_A	220.98 (N_A = 25)	81.56 (N_A = 25)	3.06 (N_A = 25)	208.04 (N_A = 25)
	STD. DEV., S_A	36.06	27.21	0.77	29.29
STATISTICAL SIGNIFICANCE TEST	CHANGE, $\lvert X_B - X_A \rvert$	9.23	12.24	1.[illegible]	4.9[illegible]
	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	8.44	7.07	0.25	7.61
	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	1.09 (D_f=40)	1.74 (D_f=42)	1.14 (D_f=3[illegible])	0.61 (D_f= 37)
	CONFIDENCE LEVEL (1 - X in %)	85%	[illegible]%	7[illegible]%	71%

N_B : NUMBER OF BEFORE - STUDY TEST RUNS
N_A : " " AFTER " " "
D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 1100 -> 1300 (ML)

ROUTE 3, 2.08 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC / MILE)	DELAY (~~MIN.~~ SEC / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	225^{96} ($N_B = 24$)	79^{63} ($N_B = 22$)	2^{69} ($N_B = 22$)	210^{44} ($N_B = 14$)
	STD. DEV., S_B	31^{83}	28^{90}	0^{81}	16^{05}
AFTER	MEAN, X_A	263^{14} ($N_A = 18$)	107^{88} ($N_A = 18$)	$3.^{76}$ ($N_A = 18$)	223^{99} ($N_A = 18$)
	STD. DEV., S_A	36^{92}	36^{15}	$0.^{83}$	21^{90}
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	37^{18}	28^{25}	$1.^{07}$	13^{55}
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	19^{23}	10^{52}	$0.^{26}$	$6.^{71}$
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	$1.^{93}$ ($D_f = 22$)	2^{69} ($D_f = 34$)	$4.^{11}$ ($D_f = 38$)	$2.^{02}$ ($D_f = 32$)
	CONFIDENCE LEVEL (1 - X in %)	97%	99%	100%	97%

N_B : NUMBER OF BEFORE-STUDY TEST RUNS

N_A : " " AFTER " " "

D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 1330 - 1530 (Mz)

ROUTE 3 ; 2.08 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC / MILE)	DELAY (~~MIN.~~ SEC / MILE)	STOPS (NO. / MILE)	FUEL (GAL. ML / MILE)
BEFORE	MEAN, X_B	252.27 (N_B = 23)	99.98 (N_B = 22)	3.70 (N_B = 22)	229.15 (N_B = 12)
	STD. DEV., S_B	57.52	34.20	0.99	18.98
AFTER	MEAN, X_A	258.32 (N_A = 16)	100.00 (N_A = 16)	3.58 (N_A = 16)	218.15 (N_A = 16)
	STD. DEV., S_A	31.14	30.57	0.72	22.00
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	6.05	0.02	0.12	11.00
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	14.30	10.56	0.28	7.76
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	0.42 (D_f = 37)	0.002 (D_f = 36)	0.43 (D_f = 38)	1.42 (D_f = 28)
	CONFIDENCE LEVEL (1 - X in %)	66 %	< 60%	66%	91%

N_B = NUMBER OF BEFORE-STUDY TEST RUNS

N_A = " " AFTER-STUDY " "

D_f = DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 1600 – 1800 (PM)

ROUTE 3 ; 2.08 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC. / MILE)	DELAY (~~MIN.~~ SEC. / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	$272^{\underline{21}}$ ($N_B = 20$)	$114^{\underline{74}}$ ($N_B = 17$)	$3^{\underline{53}}$ ($N_B = 17$)	$223^{\underline{65}}$ ($N_B = 15$)
	STD. DEV., S_B	$36.^{\underline{08}}$	$34^{\underline{49}}$	$0^{\underline{85}}$	$46^{\underline{99}}$
AFTER	MEAN, X_A	$264^{\underline{67}}$ ($N_A = 23$)	$110^{\underline{56}}$ ($N_A = 23$)	$3^{\underline{28}}$ ($N_A = 23$)	$203^{\underline{66}}$ ($N_A = 23$)
	STD. DEV., S_A	$29^{\underline{74}}$	$27^{\underline{13}}$	$0^{\underline{50}}$	$15^{\underline{87}}$
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	$7^{\underline{54}}$	$4^{\underline{18}}$	$0^{\underline{25}}$	$19^{\underline{99}}$
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	$10^{\underline{18}}$	$10^{\underline{10}}$	$0^{\underline{23}}$	$12^{\underline{58}}$
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	$0^{\underline{74}}$ ($D_f = 39$)	$0^{\underline{41}}$ ($D_f = 31$)	$1.^{\underline{08}}$ ($D_f = 25$)	$1.^{\underline{59}}$ ($D_f = 16$)
	CONFIDENCE LEVEL (1 - X in %)	76%	65%	84%	93%

N_B : NUMBER OF BEFORE-STUDY TEST RUNS

N_A : 〃 〃 AFTER- 〃 〃 〃

D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 0700 → 0900 (AM)

ROUTE 4 ; 1.93 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC / MILE)	DELAY (~~MIN.~~ SEC. / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	223^{08} ($N_B = 24$)	84^{97} ($N_B = 18$)	2^{99} ($N_B = 18$)	223^{80} ($N_B = 14$)
	STD. DEV., S_B	36^{38}	34^{99}	$0.^{73}$	23^{40}
AFTER	MEAN, X_A	231^{54} ($N_A = 25$)	85^{23} ($N_A = 25$)	$2.^{96}$ ($N_A = 25$)	$221.^{68}$ ($N_A = 25$)
	STD. DEV., S_A	31^{90}	30^{59}	$0.^{64}$	28^{81}
STATISTICAL SIGNIFICANCE TEST	CHANGE, $\lvert X_B - X_A \rvert$	8^{46}	$0.^{26}$	$0.^{03}$	$2.^{12}$
	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	9^{79}	10^{27}	$0.^{21}$	8^{50}
	$T_X = \dfrac{\lvert X_B - X_A \rvert}{S}$	$0.^{86}$ ($D_f = 48$)	$0.^{03}$ ($D_f = 35$)	$0.^{14}$ ($D_f = 35$)	$0.^{25}$ ($D_f =$ [illegible])
	CONFIDENCE LEVEL (1 - X in %)	79%	< 60%	< 60%	< 60%

N_B : NUMBER OF BEFORE-STUDY TESTRUNS

N_A : " " AFTER " " "

D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 1100 - 1300 (MI)
ROUTE 4 ; 1.93 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC. / MILE)	DELAY (~~MIN.~~ SEC. / MILE)	STOPS (NO. / MILE)	FUEL (~~GAL.~~ ML / MILE)
BEFORE	MEAN, X_B	266.79 (N_B = 33)	115.74 (N_B = 21)	3.65 (N_B = 21)	225.43 (N_B = 12)
	STD. DEV., S_B	41.96	37.15	0.70	30.02
AFTER	MEAN, X_A	268.17 (N_A = 18)	106.70 (N_A = 18)	3.72 (N_A = 18)	228.01 (N_A = 18)
	STD. DEV., S_A	18.30	17.84	0.54	13.61
STATISTICAL SIGNIFICANCE TEST	CHANGE, $\lvert X_B - X_A \rvert$	1.38	9.04	0.07	2.58
	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	8.48	9.09	0.20	9.24
	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	0.16 (D_f = 49)	1.50 (D_f = 30)	0.35 (D_f = 39)	0.28 (D_f = 15)
	CONFIDENCE LEVEL (1 - X in %)	< 60%	83%	61%	61%

N_B : NUMBER OF BEFORE-STUDY TEST RUNS

N_A : " " AFTER- " " "

D_f : DEGREE OF FREEDOM

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY Redwood City CONTROL PERIOD 1330 - 1530 (M2)

ROUTE 4 ; 1.93 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (SEC ~~MIN.~~ / MILE)	DELAY (SEC ~~MIN.~~ / MILE)	STOPS (NO. / MILE)	FUEL (ML. ~~GAL.~~ / MILE)
BEFORE	MEAN, X_B	281.63 (N_B=23)	133.40 (N_B=22)	3.60 (N_B=22)	240.30 (N_B=13)
	STD. DEV., S_B	31.07	44.45	1.10	23.39
AFTER	MEAN, X_A	269.89 (N_A=16)	109.55 (N_A=16)	3.44 (N_A=16)	225.26 (N_A=16)
	STD. DEV., S_A	33.99	33.02	0.75	24.83
STATISTICAL SIGNIFICANCE TEST	CHANGE, $\lvert X_B - X_A \rvert$	11.74	23.85	0.16	15.04
	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	10.69	12.57	0.30	8.97
	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	1.10 (D_f=32)	1.90 (D_f=38)	0.53 (D_f=38)	1.68 (D_f=28)
	CONFIDENCE LEVEL (1 - X in %)	85%	97%	70%	95%

N_B = NUMBER OF BEFORE - STUDY TEST RUNS.

N_A = " " AFTER - STUDY " "

D_f = DEGREE OF FREEDOM.

TABLE 5: ANALYSIS OF FIELD EVALUATION RESULTS

CITY *Redwood City* CONTROL PERIOD *1600 – 1800 (PM)*

ROUTE 4 ; 1.93 MILES

CONDITION		MEASURES OF EFFECTIVENESS (MOE's)			
		TRAVEL TIME (~~MIN.~~ SEC / MILE)	DELAY (~~MIN.~~ SEC / MILE)	STOPS (NO. / MILE)	FUEL (GAL. / MILE) ml
BEFORE	MEAN, X_B	275^{55} (N_B = 21)	118^{45} (N_B = 18)	3^{46} (N_B = 18)	211^{56} (N_B = 12)
	STD. DEV., S_B	44^{96}	31^{25}	0^{92}	29^{61}
AFTER	MEAN, X_A	283^{75} (N_A = 24)	127^{11} (N_A = 24)	$3.^{24}$ (N_A = 24)	224^{09} (N_A = 24)
	STD. DEV., S_A	62^{33}	55^{22}	0^{97}	33^{14}
STATISTICAL	CHANGE, $\lvert X_B - X_A \rvert$	8^{20}	8^{66}	0^{22}	12^{53}
SIGNIFICANCE	$S = \sqrt{S_B^2/N_B + S_A^2/N_A}$	16^{07}	13^{46}	0^{29}	10^{90}
TEST	$T_X = \frac{\lvert X_B - X_A \rvert}{S}$	0^{51} (D_f = 43)	0^{64} (D_f = 39)	0^{75} (D_f = 40)	1^{15} (D_f = 27)
	CONFIDENCE LEVEL (1 - X in %)	69%	74%	77%	86%

N_B : NUMBER OF BEFORE-STUDY TEST RUNS

N_A : " " AFTER " " "

D_f : DEGREE OF FREEDOM

APPENDIX B

HICOMP

Highway Congestion Monitoring Program

Congest

and

CLOG

REV. 1.0

Developed by
The State of California Deparment of Transportation
Division of New Technology & Research
Earl Shirley, Chief

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Caltrans

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Chapter 1
Congest & CLOG Background

Traffic Congestion Data Collection and Analysis System

Introduction

Traffic congestion has become a severe problem on our nation's highways. Precise reproducible measurement of congestion is necessary for both empirical studies and to validate theoretical models. This measurement can be done from a fixed sensor (such as inductive loops in the roadway) or by using a floating vehicle, a vehicle in the traffic recording actual congestion data. Caltrans has developed a computer-based system for data acquisition, analysis and presentation for floating vehicle congestion studies.

This Congestion Monitoring System consists of vehicles equipped with a laptop micro-computer to gather data as the car is driven through congested areas, and an office computer to analyze and graph this data. Caltrans has developed two complete stand-alone computer applications: one for the laptop, and one for the office system, which when used together can generate various types of tabular and graphical outputs. The traffic engineer is given wide latitude to specify such things as the scale and range used in the plots and other parameters. This system replaces an aging mechanical tachograph system which was prone to errors and required considerable data manipulation by hand. An annual savings of over $100,000 (on the average) for the Districts has been estimated for the use of this new system.

Development

The development of the Congestion Monitoring System has a history that spans several years. In late 1979, the California Energy Commission wanted to determine the fuel and time savings due to network traffic signal re-timing. They had a private consultant develop a vehicle with a data collection system that gathered data on fuel and speed. This system, which was state-of-the-art when it was developed, used a unique tape spooling technique that allowed all of the data to be collected and retrieved from a single channel digital tape drive. This tape was read back into an Apple II computer which decoded the data and tabulated a summary of the results.

In 1981, the Caltrans Division of New Technology, Transportation Materials and Research (formerly called the Translab) acquired this system in order to perform other fuel consumption studies. By 1983, the memory limitations of the Apple II were found to be too restrictive, so the analysis software was transferred over to an Apple Lisa, which was the biggest micro computer available at the time. This also allowed the development of graphical output formats to aid in the analysis of larger volumes of data.

In 1985, the Caltrans Division of New Technology, Transportation Materials and Research was using the data collection system in a research project to determine the relationship between fuel consumption, traffic volume and speed. While collecting data in the Los Angeles area, a District traffic engineer happened to notice one of the graphical output formats used in this project, and indicated that the format would be useful for his own data acquisition needs. At this time, the Districts used an old mechanical system which used a pen to mark a circular piece of graph paper which rotated as the car traveled down the road (see Figure 1). All the traffic data would then have to be read off these graphs by hand. This system was prone to errors, broke down often, and the parts are no longer available.

Unfortunately, over the years the original research system had aged considerably and almost every component had failed at one point or another and was not functional for use outside of special studies. Therefore, a number of different system configurations were considered for a replacement system. Different combinations of microcomputers, commercial data loggers, and dedicated distance measuring instruments were all considered, and software was written for some of these systems. In the end, the administrative approval process became a major deciding factor, and a dual computer system was adopted: an MS-DOS laptop for data acquisition and a Macintosh II computer for analysis and presentation. This system has largely replaced the ancient mechanical tachograph system formerly used in the Districts.

The system was developed to allow traffic engineers to analyze the magnitude, duration and location of traffic congestion on highways and city streets. It is used to monitor traffic patterns and prioritize traffic improvement projects and to determine the effectiveness of traffic systems management options.

FREEWAY OPERATION DEPARTMENT - TACHOGRAPH RECORDING

County, Route, Post Miles SD 8 PM 14.484 to 3.297

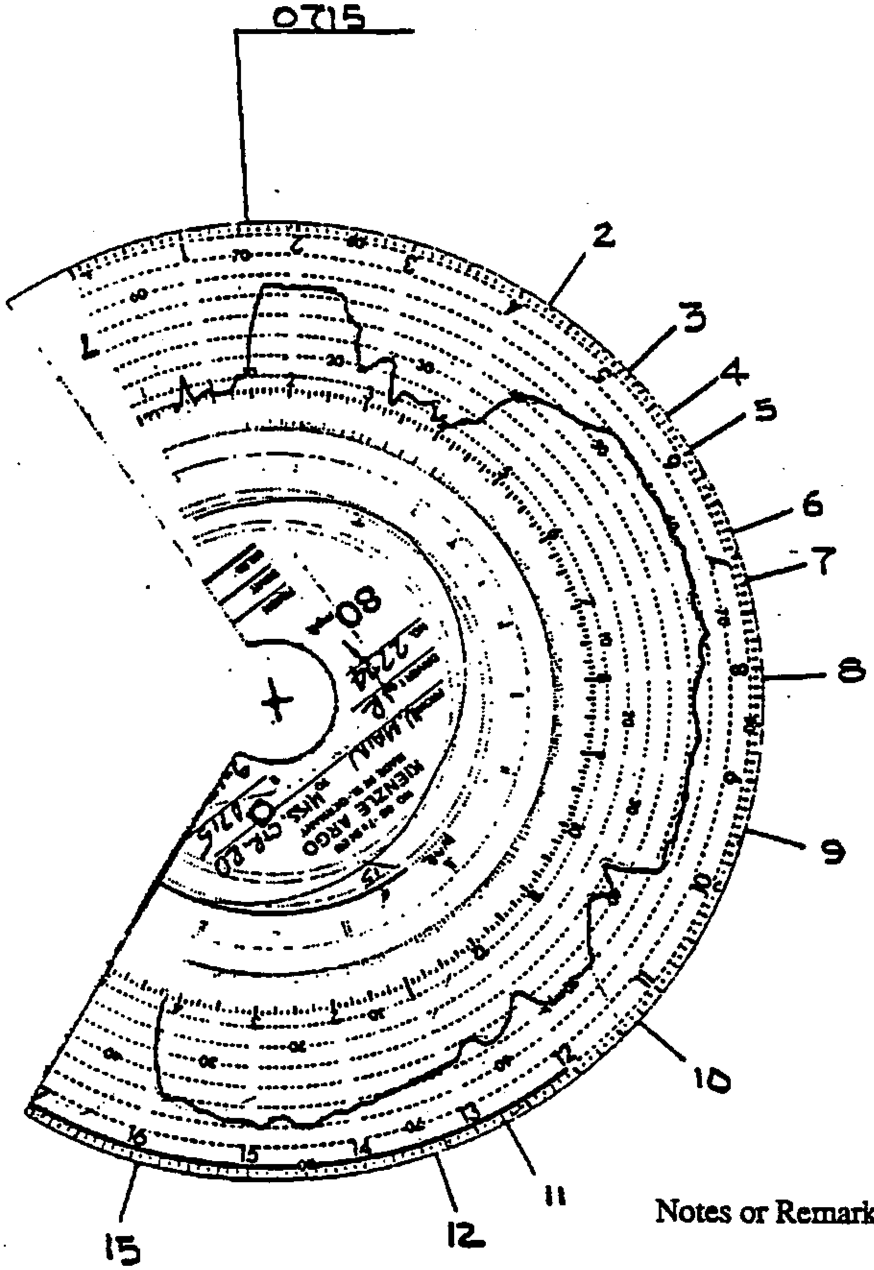
Direction: N/B S/B E/B W/B Date: 9-17-80 M TU W TH F

Weather and Light: AM PM CLEAR Lane (Median=#1) 2

Vehicle CHC No. 7274 Observer: JR

Starting Time 0715

Travel Time 14'22" 14:37



1. Main St. ON
2. Murray Dr.
3. Rte. 94 off
4. Grossmont Ctr.
5. Jackson Dr.
6. Spring St.
7. Fletcher Pkwy.
8. 70th/lk. Murray
9. College Av.
10. Warring Rd.
11. Mission Gorge ON
12. ¢ Rte. 15
13. ¢ Rte. 805
14. Stadium Way
15. Mission Ctr.

Notes or Remarks: 1. All points are off-ramp nodes unless otherwise indicated.

Figure 1 - Mechanical tachograph output from previous technology

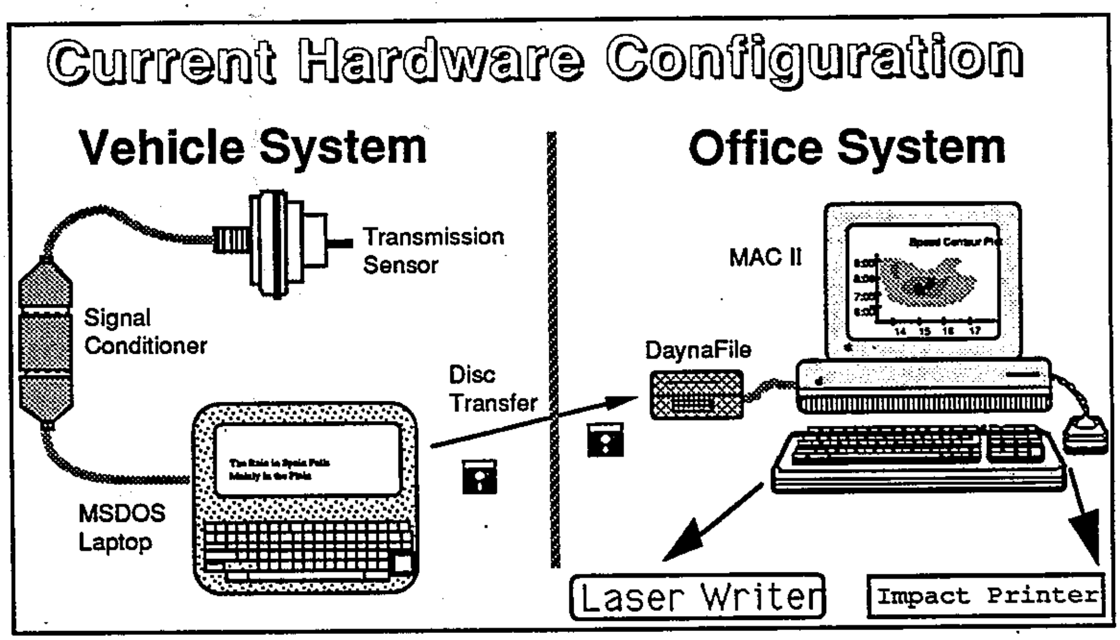


Figure 2

System Configuration

Figure 2 shows that the new system consists of basically two parts: a vehicle system and an office system. The vehicle system consists of a transducer, signal conditioner, and laptop computer. A commercially available transducer is hooked to each vehicle's transmission which outputs 12 volt pulses for every wheel revolution. This provides the system with a lineal distance resolution of approximately 6 inches. The transducer is a transmission sensor sold by Nu-Metrics Inc. This sensor is mounted in line with the speedometer cable. Any vehicle equipped with a Roadstar milemeter that operates with a transmission sensor can be modified to use for congestion monitoring.

A signal conditioner developed at Caltrans transforms the transducer's pulses into an RS232 formatted computer signal which is then read by the laptop. The signal conditioner modifies pulses from the transducer into a voltage range and signal timing that can be interpreted by a computer. This modified signal will also register when the vehicle is travelling in reverse.

The laptop's internal clock is used to record the data at one second intervals, allowing the speed and other time-related data to be determined. After each run, the gathered information is recorded onto a diskette. The controlling software on the MS-DOS laptop is **Congest.** The laptop computer can be any make that operates MS-DOS with similar BIOS specifications as the Zenith Supersports laptop computer. The laptops provided are Zenith SuperSports with the **Congest** program installed on its hard disk.

The office system consists of a Macintosh II computer, a file format translator (Dayna File), and an output device. A Macintosh was used as the office computer because it was the only micro capable of manipulating the graphic images needed by some of the output formats. The software on the Macintosh that manipulates the collected data is called the Congestion Location Output Graphics (CLOG) program.

A DaynaFile disc drive, which can read and write MS-DOS 3 1/2" and 5 1/4" disks, is currently being used by the Districts to read the laptop discs into the Mac operating system; although a modem, hardware cable, or network device such as TOPS could have been used. Also, a Macintosh IIx can read MS-DOS disks directly (by translating through the Apple File Exchange utility). Laser and impact printers are being used by the Districts for output, although pen plotters or color printers can be used to produce more dramatic results.

Chapter 2
Congest

Introduction

Congest is somewhat user-friendly because the user steps from one menu to another according to what is desired. Basically, to operate Congest, the driver must first either select an existing Location file or create a new one. Location files contain information on the county, route, District, name and postmiles of the cross streets. While operating the vehicle, the driver need only press one key at the designated start post mile indicated in the Location file to start the data collection. However, special events (flags) can also be entered through the keyboard to mark accidents, ramps, or other important data during the run. While collecting data, the laptop displays the current location and speed as the car is travelling. The driver may look at a summary of the run's delay and speeds using the laptop immediately after the data has been collected. A routine to calibrate the transducer is included in **Congest.** A detailed procedure for these steps follows.

Setting Up

To begin with, the **Congest** program must be installed on the hard disk of the laptop. Other laptops may be used if they have a hard disk or an extra floppy disk drive. If a laptop with a hard drive is used, copy the **Congest** program on the hard drive. If a laptop with two floppy drives is used, copy the laptop's COMMAND.COM file (from the DOS boot disk) and the **Congest** program on a floppy disk. The laptop can be booted up using the normal procedure and then the **Congest** program may be run.

Note: In order to operate the laptop computer, it is *strongly* recommended that the user have a working knowledge of basic MS-DOS commands.

CONGEST Version 1.0d	MAIN MENU
1 = Calculate Calibration Factor 2 = Create New Location File 3 = Start RUN 4 = EXIT Use ARROW KEYS to High-Light choice & Hit 'Enter'	

Figure 3

Operation of the Laptop

Start-up:

1) Make sure the vehicle is running. This is to protect the computer components from voltage surges.
2) Connect the signal conditioner or wiring harness in the car to the RS-232 port on the back of the laptop.
3) If there is a toggle switch, turn it ON (to C).
4) Plug the cigarette lighter adapter into the laptop (only *after* the vehicle has been started).
5) Turn the laptop ON and use the normal boot up procedure for the laptop you are using. For a detailed explanation, see Appendix 9.
6) Type **congest** and press return (the SuperSport automatically does this).
7) Choose the option you want to do. (See Figure 3.)

Note: *Do not use commas* when entering any data into any of the highlighted fields. This will cause problems when the data is read into **CLOG**. The **CLOG** program uses commas to mark the beginning and end of data fields. Using commas will result in the **CLOG** program interpreting the data erroneously and creating invalid plots.

CONGEST Version 1.0d			CALIBRATE
Run No.	Number of Pulses	Actual Road Miiles	Calibration Factor
1.			
Hit <Space Bar> to start Calibration run			

Figure 4

To Calculate the Calibration Factor:

1) From the MAIN MENU (see Figure 3), select **Calculate Calibration Factor** by highlighting it and pressing return or pressing the number 1. (See Figure 4.)
2) Press the space bar to begin the run.
3) Drive to the end of the calibration course.
4) Press the space bar to stop the run.
5) Enter the actual distance travelled in miles and press return.
6) Press Y if another run is desired, return to the beginning of the calibration course, and go to step 2; or press N if you want to stop calibration runs (the program will average the factors for the runs and enter it in the master file).

Note: Calculating the calibration factor should be done on a *pre-measured* course that allows the vehicle to begin and end from a *stopped* position. The mark at the end of the calibration course should be aligned in the same location on the vehicle as it was at the start of the run. At least one mile is recommended. The longer the run, the greater the accuracy.

CONGEST Version 1.0d				NEW LOCATION
	Dist.	County	Route	
Location Name	1		1	

	Description	Post Mile		Description	Post Mile
START---		0.000			
Link 1.		0.000	Link 11.		0.000
Link 2.		0.000	Link 12.		0.000
Link 3.		0.000	Link 13.		0.000
Link 4.		0.000	Link 14.		0.000
Link 5.		0.000	Link 15.		0.000
Link 6.		0.000	Link 16.		0.000
Link 7.		0.000	Link 17.		0.000
Link 8.		0.000	Link 18.		0.000
Link 9.		0.000	Link 19.		0.000
Link 10.		0.000			
			END---		0.000

Fill in data fields & Hit any F-KEY when done

Figure 5

To Create a Location File:

1) From the MAIN MENU (see Figure 3), select **Create New Location File** by highlighting and pressing return or pressing the number 2. See Figure 5.
2) Fill in the highlighted areas. Press Enter after each entry. The file name should be descriptive of the location where the runs are being made (i.e. SLO14N for San Luis Obispo County, at Post Mile 14, in the north-bound lane). Descriptions for the START, END, and LINK locations should be points that are easy to identify (crossroad, post mile, etc.). Links should be located no closer than 0.5 mile if possible (for output display purposes). Separate Location Files should be created for data of each direction of traffic (i.e, west-bound, east-bound). Use *only 19 links* in **Congest** version 1.0, *even though it seems to accept 20*.
3) Check the highlighted fields to assure the data is correct.
4) If the data is correct, press any F key.

CONGEST Version 1.0d				LOCATION MENU
LOCATION	DESCRIPTION			
HWY405NB	12 ORA 1	0	14.041	
HWY405SB	12 ORA 1	14.041	0	
US5NB	12 ORA 1	0	14.041	
US5SB	12 ORA 1	14.041	0	

Use ARROW KEYS to choose location & Hit 'Enter'

Figure 6

To make a data collection Run (Start RUN):

Currently the **Congest** program is configured to collect data in one direction only. Bi-directional data *can* be obtained by using two separate location files, one for each direction. The first method described is to enter the program and make successive directional runs. The second method described is to make runs in opposite directions (bi-directional) and switching files (Location Files) after each run. Each method has specific benefits and drawbacks and is described below

It is recommended that data collection runs be limited to 12 miles if they are to be used for contour plots in the **CLOG** program. If a run was started accidentally or the wrong location file was entered, follow the steps through the program to get back to the MAIN MENU and restart. ***Do not*** turn the computer off since this contaminates the data disk and then **Congest** will not start up using this disk.

To make Successive Runs:

1) From the MAIN MENU (see Figure 3), select **Start RUN,** by high-lighting it and pressing return or press the number 3. (See Figure 6.)

CONGEST Version 1.0d RUN MENU

CALIBRATION FACTOR: CAR ID:

DRIVER Last Name: First Name:

COMMENTS: (Weather, etc.)

LOCATION: HERE 1 2 1 1 5

When High-Lighted fieldsare correct Hit any F-KEY to proceed

Figure 7

2) Select the desired location by highlighting it and pushing the return key. (See Figures 6 and 7.)
3) Check the highlighted fields to assure the correct data is in the highlighted fields. (car ID should be a letter)
4) If the data is correct, press any F key.
5) Begin the RUN. This can be done by accelerating to highway speed and pressing the space bar as you pass the starting point, or pressing the space bar before accelerating from the starting point.
6) Use the F1 through F9 keys to mark FLAGS, a point of interest that is determined by the user. It is recommended that flags F1-F6 be used to mark lane numbers and flags F7-F8 be used to mark roadside events, such as accidents or "rubber-necking" incidences. The flag F9 could be used to mark "click points", or synchronized marks during a run such as gore points or over-crossings.
7) Press the space bar at the location of the end of the run.
8) Return the vehicle to the starting point, select **Start another RUN** by pressing return or the number 1. (make sure **Start another RUN** is highlighted *before* pressing return) See Figure 8.
9) Repeat step 5 until completion of data collection period.

When the data collection runs are completed for the period, select **Return to MAIN MENU** by highlighting it and pressing return or pressing the number 4. (See Figure 8.) Select EXIT by highlighting it and pressing return or pressing the number 4.

This method of successive runs requires extra time and travel to gather data for both directions. However, creating a SPEED CONTOUR PLOT is much simpler through the **CLOG** program when data is gathered by this method.

Note 1: In version 1.0 of **CLOG**, a run which has more than 2400 seconds of data collected may cause the program to crash if a tachograph output is requested. Therefore, it is suggested that if the data of the multiple runs add up to more than 40 minutes, the data should be broken down into multiple data files. This would require going back to the main menu, selecting the same location file, and then starting another run. This is *not* necessary if a tachograph is not the required output.

Note 2: Because the computer records data only once every second, better positional resolution will be achieved at lower speeds. For example, run and link distances will have an accuracy (resolution) of 10ft when travelling at 10ft/sec, but only 100 ft when travelling at 100ft/sec.

To make Opposing Runs (bi-directional):

1) From the MAIN MENU (see Figure 3), select **Start RUN,** by highlighting it or press number 3. See Figure 6.
2) Select the desired location file by highlighting it and pushing the return key. (See Figure 6.) There should be a separate Location File for north-bound (NB) data vs. south-bound (SB) data, or east-bound (EB) vs. west-bound(WB). See Figure 7.
3) Check the highlighted fields to assure the correct data is in the highlighted fields. (car ID should be a letter)
4) If the data is correct, press any F key.
5) Begin the RUN. This can be done by accelerating to highway speed and pressing the space bar as you pass the starting point, or pressing the space bar before accelerating from the starting point.
6) Use the F1 through F9 keys to mark FLAGS, a point of interest.
7) Press the space bar at the location of the end of the run.
8) Select **Return to MAIN MENU** by highlighting it and pressing return or pressing the number 4. See Figure 8.
9) To make opposing run, repeat the procedure starting from step 1 until completion of data collection period.

CONGEST Version 1.0d	RUN SUB-MENU

1 = Start another RUN
2 = Display FLAG summary
3 = Display LINK summary
4 = Return to MAIN MENU

High-Light your choice with ARROW KEYS & Hit 'Enter'

Figure 8

When the data collection runs are completed, select **Return to MAIN MENU** by highlighting it and pressing return or pressing the number 4. Select EXIT by highlighting it and pressing return or pressing the number 4.

This method is the most efficient use of time and travel in the field. However, it requires an extremely cumbersome process to create a SPEED CONTOUR PLOT.

To display FLAG summary: After a run has been made, press number 2 from the RUN SUB-MENU. See Figure 8.

To display LINK summary: After a run has been made, press number 3 from the RUN SUB-MENU. See Figure 8.

Note: Displaying FLAG summary or LINK summary will only be for the runs that have just been collected.

To make Backup disks: It is *extremely important* after completing data collection runs at the location, to back up the disk.

1 Make sure the congest program will start up with the Data disk.
2) Type DISKCOPY and press enter.
3) The laptop will prompt you to enter the source drive name and the destination drive name. For dual floppy drives, enter B. For laptops with a hard disk, the floppy drive is A.
4) The laptop will prompt you to place a *formatted* disk into the disk drive. The data disk used to make the data collection runs is the SOURCE disk.
5) When prompt asks if you want to make another copy, press N (no) and enter.

Chapter 3
CLOG

Introduction

The Congestion Location Output Graphics program, **CLOG**, changes vehicle congestion data into useful information. **CLOG** runs on a Macintosh II computer using the data that was gathered from a vehicle equipped with a transducer and an MS-DOS laptop with the **Congest** program. The first release of **CLOG** (version 1.0) can produce single and multiple tachographs, delay plots, summaries of flags and links for various areas, and can *aid in the creation of contour plots*. Various options are provided to allow the output to be enhanced while still providing continuity between different users.

This procedure assumes the user has a working knowledge of Macintosh computers. It is *strongly* recommended that new users complete the self-guided Apple Tour. This tour is on a diskette that is shipped with every Macintosh computer.

Setting Up

CLOG should reside on the hard disk of the Macintosh. If this has not been done, create a folder named CLOG on the hard disk and copy the **CLOG** program into this folder.

Note: The DaynaFile must be installed prior to using it. Refer to the DaynaFile Guide if the hardware and software have not been installed. *It is recommended that the software be installed on the hard disk.*

After the *first* collection of data (with **Congest**), create a folder to hold all the congestion data (name the folder "Congestion Data"). Insert the MS-DOS data disk (from the laptop) into the DaynaFile drive. A folder may be created by dragging the icon for the MS-DOS disk onto the desktop. The untitled folder may be renamed.

Click and drag  UNTITLED **to the hard disk directory.**  UNTITLED **appears.**

This step eliminates the need to copy each of the location folders into the congestion folder. The congestion data folder should hold the location folders. There should be one folder for *each* location. The location folder on the hard disk should contain a location file (i.e. HWY101.LOC), a folder for each day *and* period that data has been collected and transferred from the MS-DOS disk, and the delay files (i.e. HWY101PPM.Delay for the location called HWY101 and afternoon data) that have been created by the **CLOG** program.

For *subsequent* data collection, insert the MS-DOS data disk (from the laptop) into the DaynaFile drive. Copy the folder for the desired date and location (this will include all runs made that day) from the MS-DOS disk onto the hard disk (into a folder with the location's name). How to copy a folder is discussed below. The location file does not need to be transferred from the MS-DOS disk to the hard disk of the Macintosh if it already exists on the hard disk.

Folders are named using the date, period, and car id for the data that was collected. For example, 123188PC stands for December 31, 1988, pm, and car id 'C'. The files are named using the date, period(A for am, P for pm), car id, plus an extension with the file id, and run number where the file id is D for the data file, F for the flag file, and H for the header file (i.e. 123188PC.D02 stands for December 31,1988, PM, car 'C', data file, and run 2).

To copy a folder:

1. Double click the icon for the UNTITLED disk on the right side of the screen. The disk can be renamed (for example, SLO101) by clicking the icon once and typing the new name.

Click 

then type SLO101 and press enter.

2. Click the icon of the folder you want to copy to, so as to open it.
3. Drag the folder to the CLOG folder on the hard disk.
4. Release the icon.

Double click 

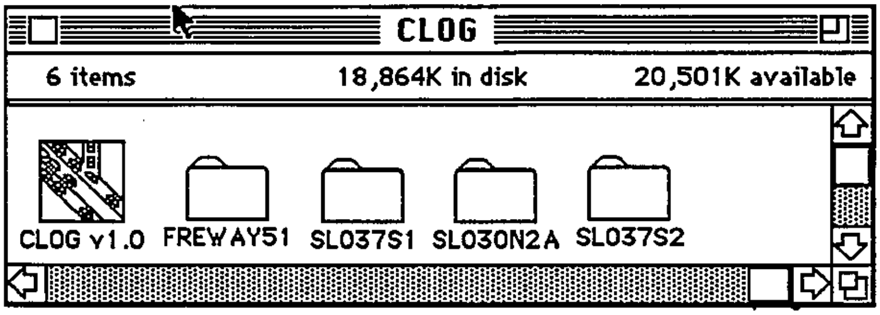
then drag 

and 

to 

Note: When copying the location file into the CLOG folder, be sure to copy it into the appropriate location folder. From the desktop, just drag SL037S2.LOC into the SLO3732 folder.

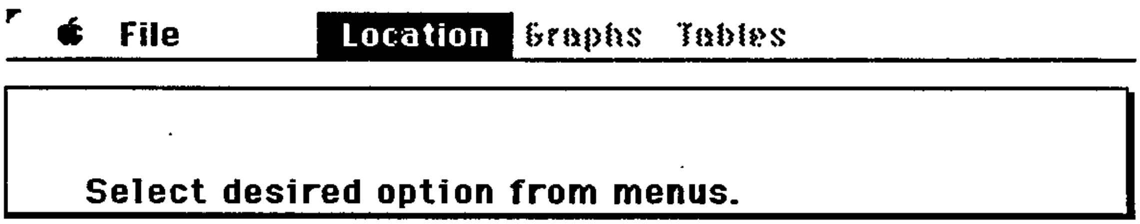
Running CLOG



Now you are ready to run the **CLOG** program. Double-click the icon labeled CLOG v1.0. You will then be asked to select an option. Your option choices are as follows:

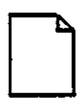
I. To create a Location File:

1) Select **Create New Location File** under the Location Menu.



2) Enter location information. For **CLOG v1.0**, a maximum of **19** links are allowed. If more than 19 are entered, the program will not operate correctly.
3) Click on OK to save the file.

Note: It is recommended that Location files be created in **CLOG** and then transferred back to the MS-DOS disk for **Congest** (drag the location file to the DOS disk icon). Although both **Congest** and **CLOG** can create Location files, only **CLOG** can edit them once they are created.

Drag location file  SL037S.LOC **to the DOS disk**  UNTITLED

However, in **CLOG v1.0**, before transferring the Location file, it must be edited through a word processor such as MS- Word or MacWrite: all quotes (") must be replaced by a space, a carriage return must be inserted at the end of the last line, and there must be a comma (,) inserted on a new last line. Then save this edited Location file as a *text* file (MS-Word: **File Format... Text Only;** MacWrite: **Save As: Text**). Then the location file is ready to be transferred to **Congest**.

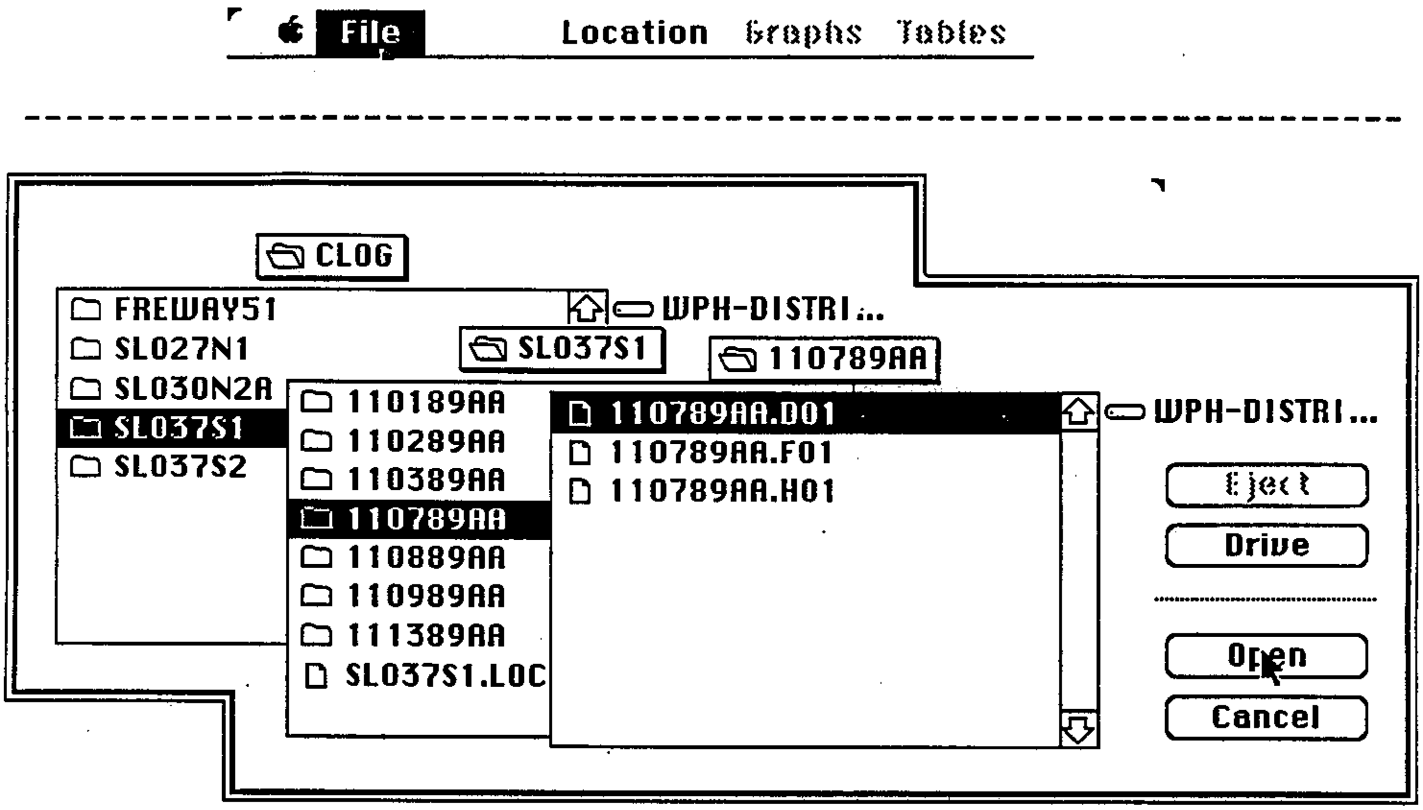
Location File generated in **CLOG v 1.0**	Location File edited in MS-Word, ready to be transferred to **Congest**
"FREWAY51",3,"SAC",51,1,3	FREWAY51 ,3, SAC ,51,1,3
" ","E ST. ON",1.579	, E ST. ON ,1.579
" ","MARCONI OFF",5.349	, MARCONI OFF ,5.349
" ","ELVAS U.P.",2.429	, ELVAS U.P. ,2.429
" ","RTE. 160 JUNCT",4.09	, RTE. 160 JUNCT ,4.09
" ","EL CAMINO OFF",4.916	, EL CAMINO OFF ,4.916
	,

II. To edit a Location File:

1) Select **Edit Location File** under the location menu.
2) Choose the location file to be edited.
3) Make the desired changes.
4) Click on OK to save the file.
5) Remember to update the copies of the location file that exist on any MS-DOS disks.

III. To produce a plot of the data gathered (tachograph or contour):

1) Open the desired data file by selecting **Open Data File** under the File menu and choose the location folder, then the date folder, then any of the files with the desired run number.



2) Select the desired plot: **Single Tachograph, Multiple Tachographs**, or **Contour Plots**, from the Graphs menu.
3) Choose the desired options for the output.
4) Select the destination for the created plot: screen, clipboard, and/or printer.
5) See Appendix 1 for an example of Multiple Tachographs.

Note 1: The contour plot output needs to be copied to the clipboard and finalized in a graphic editor. This is discussed in the next section.

Note 2: The multiple tachograph plot and contour plots must be fit to two set scales; therefore, a distance of more than 12 miles will not fit on one page. However, the single tachograph plot is *not* limited by distance, rather, the data must not exceed 2400 seconds. Single tachograph plots will print on multiple pages.

IV. To produce a Summary Table:

1) Open the desired data file by selecting **Open Data File** under the file menu and choose the location folder, then the date folder, then any of the files with the desired run number.
2) Select the desired table: **Run Delays, Flag Summary,** and **Link Summary,** from the Tables menu. See Appendix 2, 3 and 4 for examples of Summary Tables.
3) Choose the desired options for the output.
4) Select the destination for the created plot: screen, clipboard, and/or printer.

V. To create or update a Delay File:

1) Select **Update Delay File** under the File menu.
2) Open the data file to be added to the delay file.

Note: If the data from the selected data file has already been added to the Delay File, the request will be ignored.

VI. To plot the Delay File:

1) Select **Open Location Delay File** under the File menu.
2) Choose the delay file to be plotted (file will end with **.Delay**).

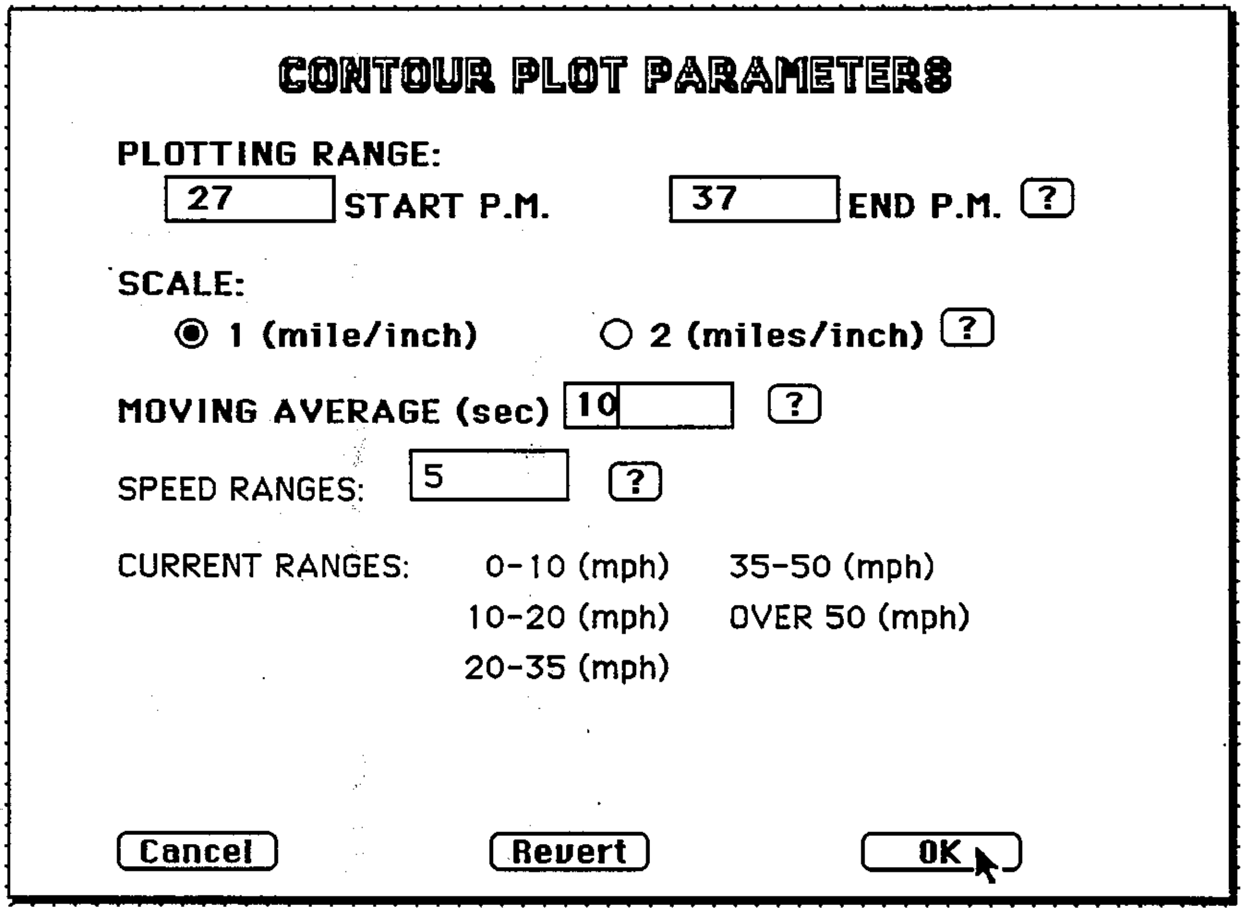
3) Select **Location Delay Plot** under the Graphs menu.
4) Select the destination for the created plot; screen, clipboard, and/or printer.
5) See Appendix 4 for a sample Delay Plot.

Note: A Delay file must be created before attempting to use the Open Location Delay File.

Speed Contour Plots

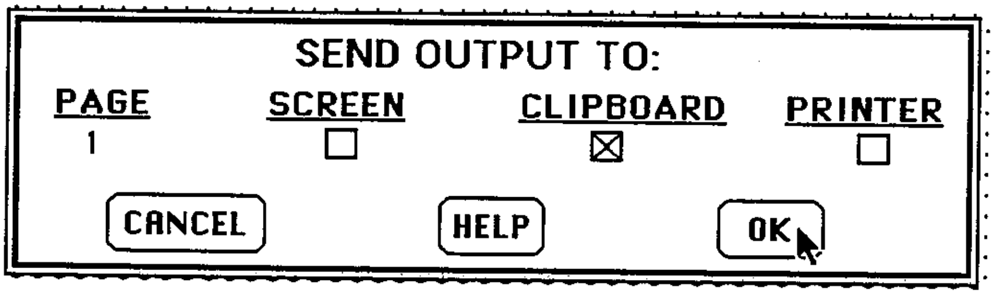
To create a true speed contour plot, the user must switch back and forth between **CLOG** and and a graphic editor, such as MiniCad*. This is very simple if the user is running Multifinder on the Macintosh instead of Finder. **CLOG** draws the contour plots and stores them in the clipboard. MiniCad combines the contour plots and allows the user to manipulate and edit the graphic data. The final product should look like an ink blot with different densities that reflect various degrees of congestion. The darkest color (black for grayscale, or user-selected color) indicates the heaviest congestion. Legends and other information are added to make the graph easy to understand. See Appendix 6 for an example of a contour plot created in CLOG and Appendix 7 for a completed contour plot edited in MiniCad.

To create a complete contour plot, the user should have a good working knowledge of MiniCad or any other graphic editor which may be used to create the contour plot, as long as multiple layering is available. MiniCad is a quite sophisticated graphic editor that contains many advanced features that may seem overly complicated to a beginning user.



1) Begin by creating a contour plot in CLOG.

   a) Open the desired data file by selecting **Open Data File** under the File menu and choosing the Location Folder, then the Date Folder, then any of the files with the desired run number.
   b) Select **Contour Plot** from the Graphs menu.
   c) Select the plotting parameters:
      i) Plotting range (beginning and ending post miles of desired plot) : click on the window and edit the text.
      ii) Horizontal scale (1" = 1 mile or 2 miles) : click the desired scale.
      iii) Moving average (time interval, or number of consecutive seconds, used to determine vehicle speeds) : select from 10 to 100 seconds.



The default value of 40 seconds is recommended.

iv) When selections have been made, click on OK.

v) The contour plot will flash on the screen for a moment and then the selection window will appear. Click on CLIPBOARD and then OK.

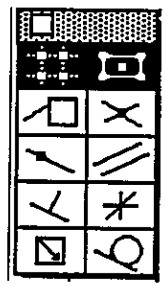
d) When window appears again, click CANCEL, then switch from the CLOG program to MiniCad through Multifinder.

2) Create a file in MiniCad.

a) Open the MiniCad +2.0 application. (Make sure this has been installed; this may be done from the MiniCad+2.0 rsrc folder by double clicking MiniCad+ Installer.)

i) Under the **Page** menu, **Set Grid** to some course setting, such as 1/4".

ii) Turn "Snap to Grid" ON. This is done with the palette shown on the right, clicking the correct tools so that they are selected and shown black.



iii) Under the == menu, turn **Show Other Layers** ON and turn **Gray Other layers** OFF.

b) Select **Layers...** under the == menu.

c) Create a new layer (use month, day, year; i.e. 112589) and click OK.

d) Select **Paste** under the Edit menu.
Press G to group all as one object.

e) Move plot to the desired location on the page. It should be placed exactly over any existing plot. (This will be easy if the "Snap to Grid" is ON.)

f) Select **Save as** under the File menu.

g) Type a name that identifies the location of the contour plot and click Save.

h) Switch from Minicad to the CLOG program through Multifinder.

3) Create another contour plot for a different date in **CLOG**. Send the output to the clipboard.

4) Through Multifinder, switch to the MiniCad file that was created.
   a) Follow steps 2b through 2f.
   b) Select **Save** from the File menu.
   c) Switch from MiniCad to **CLOG** through Multifinder.

5) Repeat steps 3 and 4 until all desired contour plots are transferred to the MiniCad file.

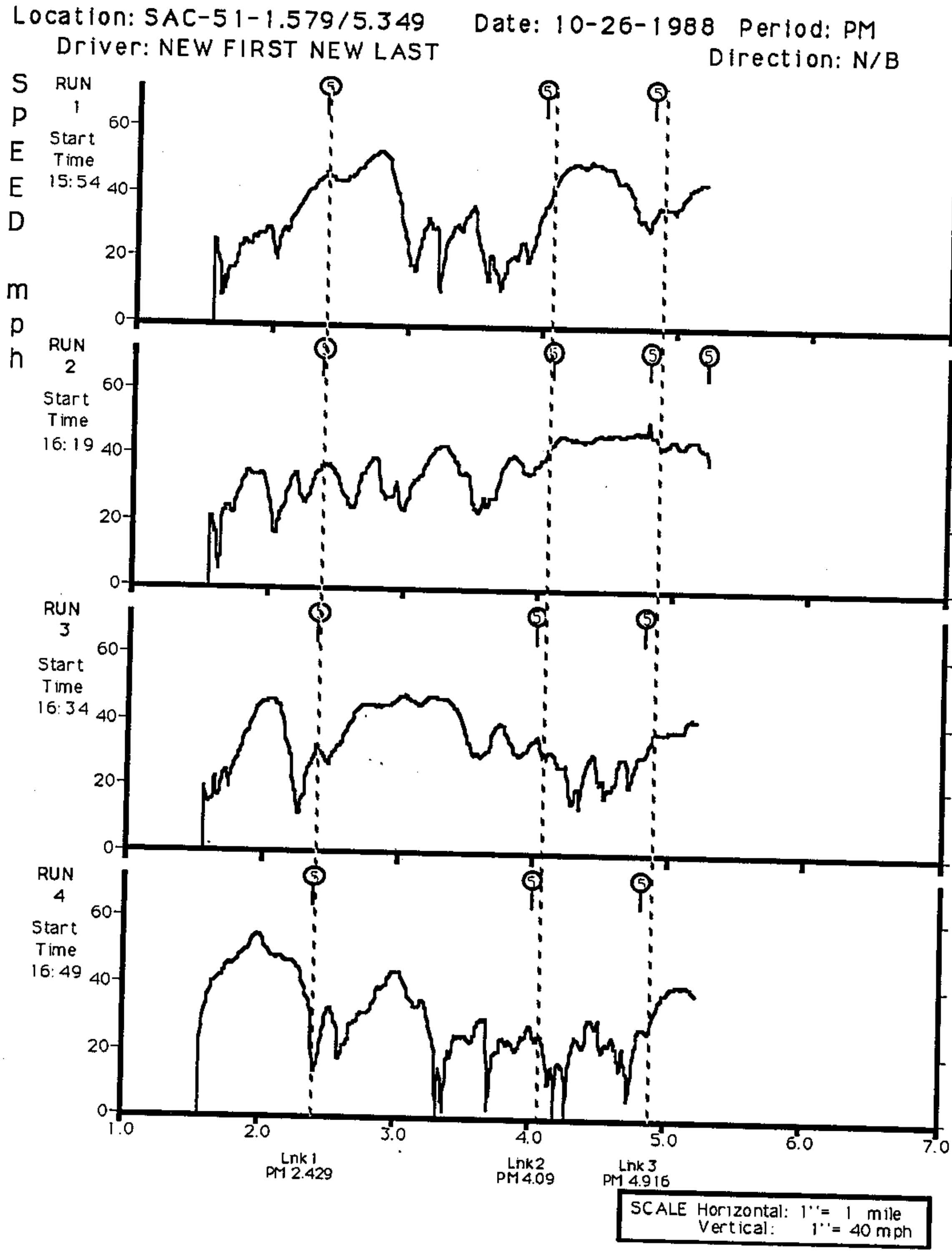
6) On a *separate* layer, create scales and legends for the plot.
   a) Create a layer for the legend and name it.
   b) Using the graphic commands, create a legend and label the axes.

7) Complete the contour plot.
   a) On a separate layer, use the freehand tool to draw the outlines of the speed contours using the **CLOG** speed lines as templates.
   b) Fill in the contours with the appropriate fill pattern.

8) Save the file (the completed contour plot) before closing or quitting. See Appendix 7 for an example.

Example CLOG Outputs

TACHOGRAPHS



Example 1 - Example of Multiple Tachographs

FLAG SUMMARY TABLE

Location: SAC-51-1.579/5.349 Date: 10-26-1988 Period: PM
Driver: NEW FIRST NEW LAST Run: 1 Direction: N/B

NAME	POSTMILE	CLOCK	DISTANCE (feet)	TIME (sec)	SPEED (mph)	AVERAGE DELAY 35mph (sec)	AVERAGE DELAY 50mph (sec)
E ST. ON	1.579	15:54:10					
			4328	119	25	35	60
Flag 5	2.399	15:56: 9					
			8560	215	27	48	98
Flag 5	4.020	15:59:44					
			4197	67	43	0	10
Flag 5	4.815	16: 0:51					
			2124	38	38	0	9
End of Run	5.217	16: 1:29					
		RUN TOTALS:	19208	439	30	83	177

Example 2 - Example of a Flag Summary Table

LINK SUMMARY TABLE

Location: SAC-51-1.579/5.349 Date: 10-26-1988 Period: PM
Driver: NEW FIRST NEW LAST Run: 1 Direction: N/B

NAME	POSTMILE	CLOCK	DISTANCE (feet)	TIME (sec)	SPEED (mph)	AVERAGE DELAY 35mph (sec)	AVERAGE DELAY 50mph (sec)
E ST. ON	1.579	15:54:10					
			4528	122	25	34	60
ELVAS U.P.	2.436	15:56:12					
			8761	219	27	48	100
RTE. 160 JUNCT	4.096	15:59:51					
			4362	71	42	0	12
EL CAMINO OFF	4.922	16: 1: 2					
			1558	27	39	0	6
End of Run	5.217	16: 1:29					
		RUN TOTALS:	19208	439	30	82	177

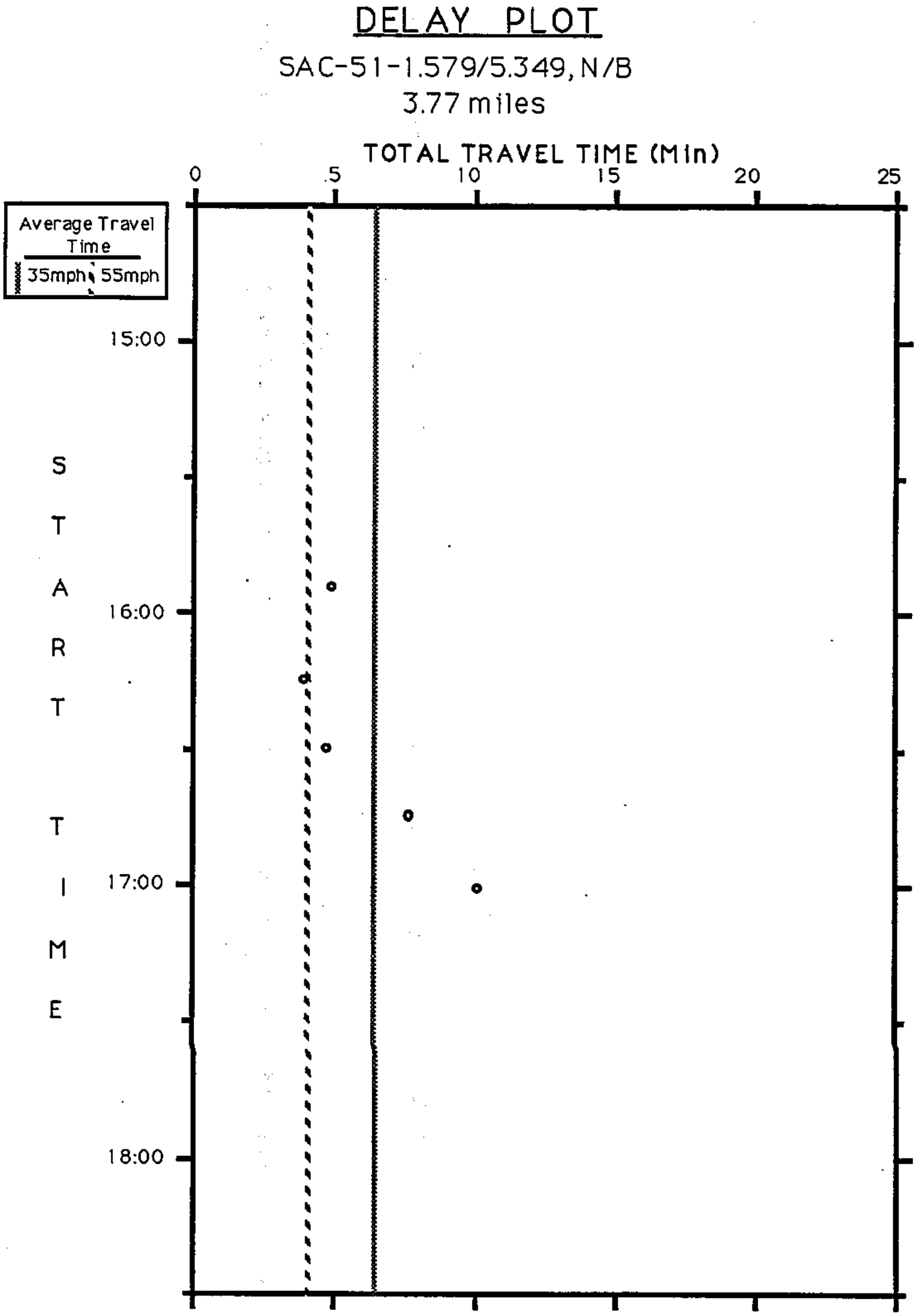
Example 3 - Example of a Link Summary Table

DELAY TABLE (Below 35mph)

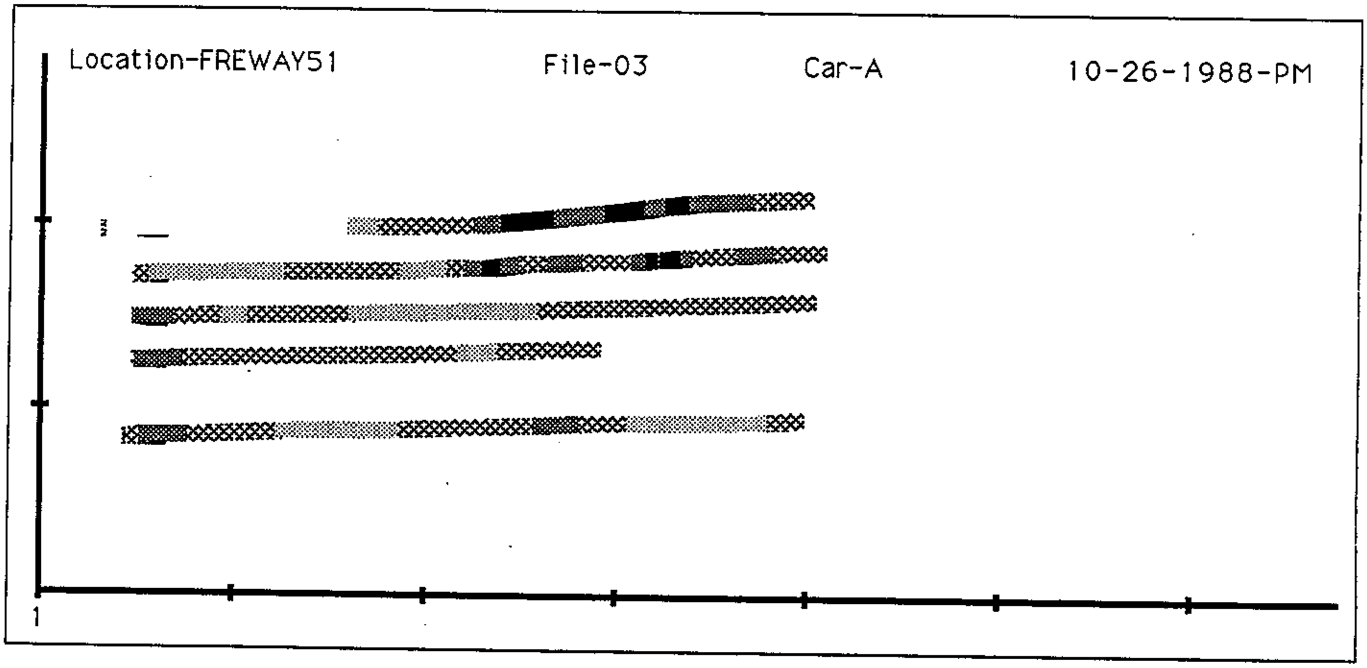
Location: SAC-51-1.579/5.349 Date: 10-26-1988 Period: PM
Driver: NEW FIRST NEW LAST Run: 1 Direction: N/B

Start PM	End PM	Start Time	End Time	Total Seconds	Total Feet
1.579	2.215	15:54:10	15:55:52	102	3358
2.964	3.492	15:56:52	15:58: 9	77	2791
3.512	4.030	15:58:11	15:59:44	93	2734
4.701	4.862	16: 0:37	16: 0:55	18	850
4.952	5.010	16: 1: 4	16: 1:10	6	310
			RUN TOTALS:	296	10043

Example 4 - Example of a Run Delay Table



Example 5 - Example of a Delay Plot



Example 6 - Example of a Contour Plot speed lines generated in CLOG

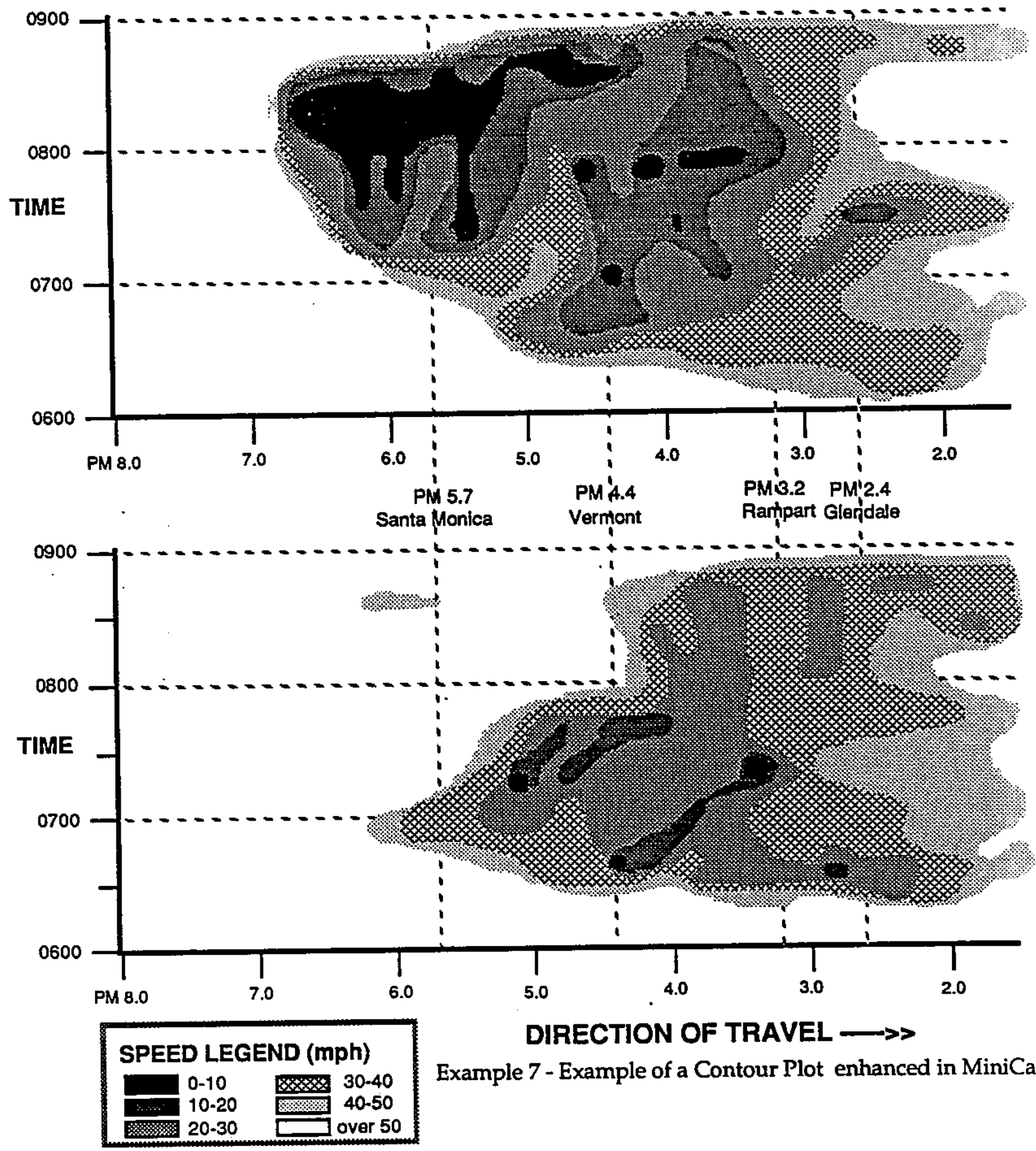
Note: Vertical tick marks are at 1 hour increments (1" = 1 hour). Horizontal tick marks are at 1 inch increments (1" = 1 mile or 2 miles, depending on the scale selected).

The number in the lower left hand corner, next to the lower left tick mark, indicates the post mile.

Speed Contour Plots

Southbound Hwy 101, Los Angeles
Morning

Data Dated: 05/14/85 - Upper Plot 05/15/85 - Lower Plot



Example 7 - Example of a Contour Plot enhanced in MiniCad

CLOG and Congest File Types

Congest creates 3 types of files for every group of runs:

DIST.FILE - Pulse%, # of pulses per second, with a value of "999" as a delineator at the start of a run and a "888" at the end of a run

FLAG.FILE - this records the keyboard events.
It's format is : **Event.num%(1), flag,time%(1), flag.dist%(1),**
Event.num%(2), flag,time%(2), flag.dist%(2), etc.
With "999" values as delineators between runs

HEADER.FILE - contains misc. header info:
First line : **Last.name$, First.name$, Location.code$, Car.code$, Date$, Comment$, Calib.factor** (ft per pulse)
Second Line : **Loc.dist%**, record # for first second of pulses in DIST.FILE for run 1
Loc.flag%, record # for first event in FLAG.FILE for run 1
actual **Run.START.time%** (HH:MM:SS) for first run
Cumulative **run.dist%** for first run
Cumulative **run.time%** for first run
Garbage.String$ (total number of flags per run)
<u>Second Line is repeated once for each run</u>

Additionally, a Location.File can be created by Congest or CLOG

LOCATION.FILE - one is created for each data collection area
First Line : **Code$, District%, County$, Route%, Sign%** (in creasing or decreasing PM), **Numlinks%**
Second Line : **Garbage.string$, Start.Location$, Start.PM%**
Third Line : **Garbage.string$, End.Location$, End.PM%**
Forth Line : **Garbage.string$, Link.Location$, Link.PM%**

<u>Forth Line is repeated once for every Link</u>

All files are text files and can be edited with any text editor.

Booting Congest on a Laptop Computer

Congest v1.0

Name	Size	Kind	Last Modified	
AUTOEXEC.BAT	1K	document	Mon, Oct 3, 1988	2:02 PM
BRUN40.EXE	76K	document	Thu, Oct 8, 1987	5:57 PM
COMMAND.COM	24K	document	Fri, Sep 4, 1987	2:37 PM
CONGEST.EXE	61K	document	Wed, Oct 26, 1988	9:00 AM
COUNTER.COM	1K	document	Mon, Apr 18, 1988	2:05 PM
COUNTER.EXE	1K	document	Mon, Apr 18, 1988	2:04 PM
DISKCOPY.COM	7K	document	Fri, Aug 21, 1987	10:21 AM
FORMAT.COM	12K	document	Wed, Mar 23, 1988	10:37 AM
LABEL.COM	3K	document	Mon, May 2, 1988	3:00 PM
MODE.COM	15K	document	Thu, Apr 14, 1988	8:54 AM
RTCLOCK.COM	3K	document	Fri, Oct 16, 1987	10:33 AM
STARTUP.EXE	4K	document	Tue, Oct 25, 1988	5:26 PM

The **Congest** disk shipped to the Districts contains the files listed above. For laptop computers with two disk drives, insert the disk in the drive and turn the computer on. It will automatically go directly to the Congest program. For laptops with a hard drives, create a directory called Cong.

C:\> MD CONG

Then change to the new CONG directory.

C:\> CD CONG

For the *first* time running the program, type AUTOEXEC. This will run the AUTOEXEC batch file (autoexec.bat) needed to insure the proper loading of the necessary files. Thereafter, to run the program, it is needed to change to the CONG directory, and then type CONGEST

C:\> CD CONG

C:\> CONGEST

Glossary

CLOG	The software that runs on a Macintosh computer that manipulates Congestion Data and displays graphical and tabular output.
Congest	The controlling software that runs on an MS-DOS laptop computer that collects Congestion data.
Speed Contour Plot	A 3 dimensional display of car speed vs. time and distance (post mile).
Delay Plot	The amount of delay (min.) for a vehicle vs. time of day, for a specific location.
Flag	A user-defined point of interest, such as roadside events: accidents, passing gore points or over-crossings, etc.
Flag Summary	A table that displays various speed and distance paramenters for a run, based on where the flags were inserted by the driver. The exact location and time that a flag was inserted and the distance, speed and delay from the previous flag are shown.
Link	A name of a location at a specific post mile. Several links (19) may be defined for a single run.
Link Summary	A summary table displaying the same parameters as the Flag Summary, based on Links rather than flags.
Location File	A user-defined file that contains the various data which describes the location that Congest data is collected.
Run Delay Table	A table that shows the exact location (by post miles) and time a vehicle's speed falls below 35mph.
Tachograph	A display of speed vs. distance (post mile) that a vehicle has travelled.

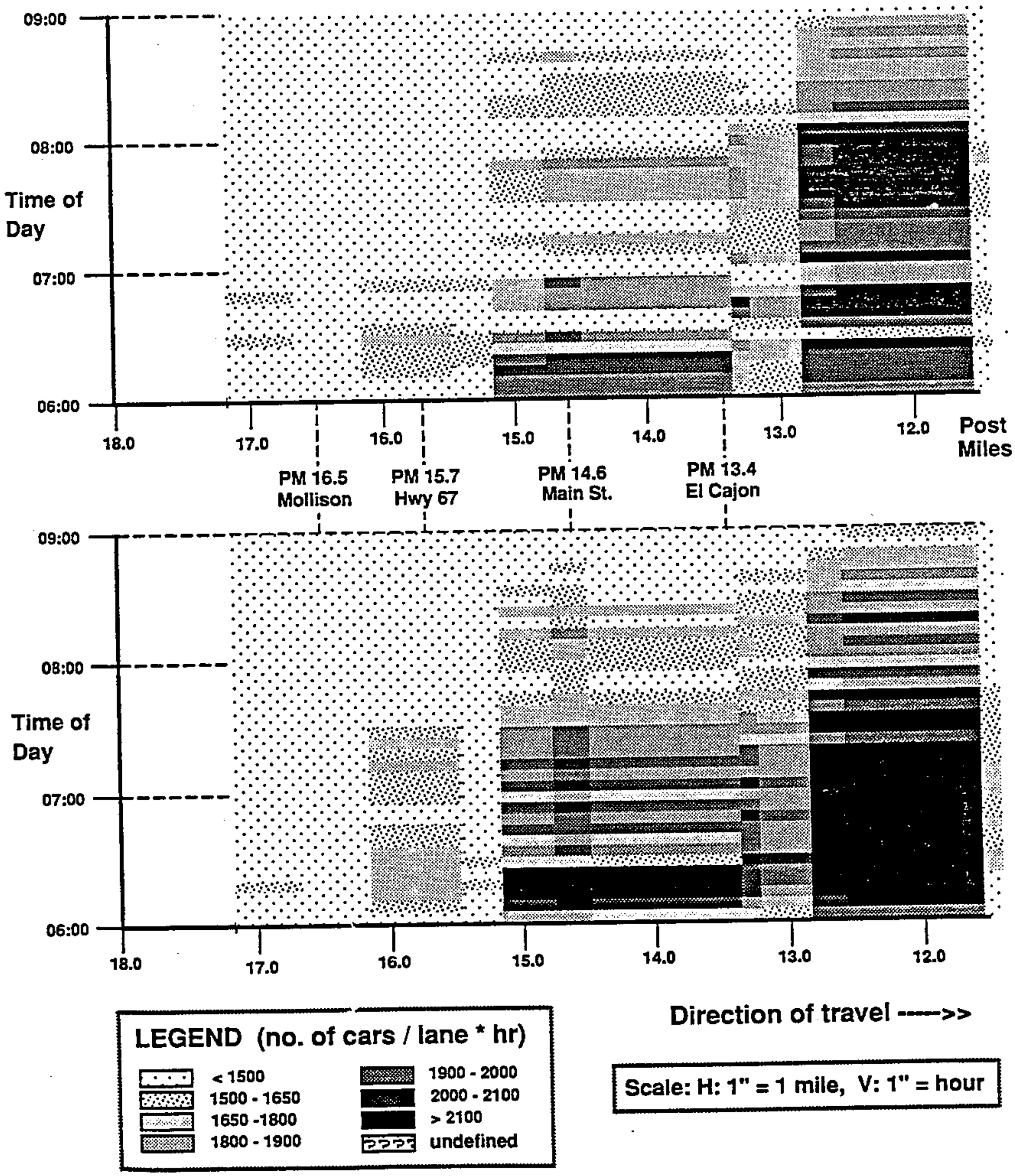
APPENDIX C

Volume Density Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/09/85 - Upper Plot 04/10/85 - Lower Plot

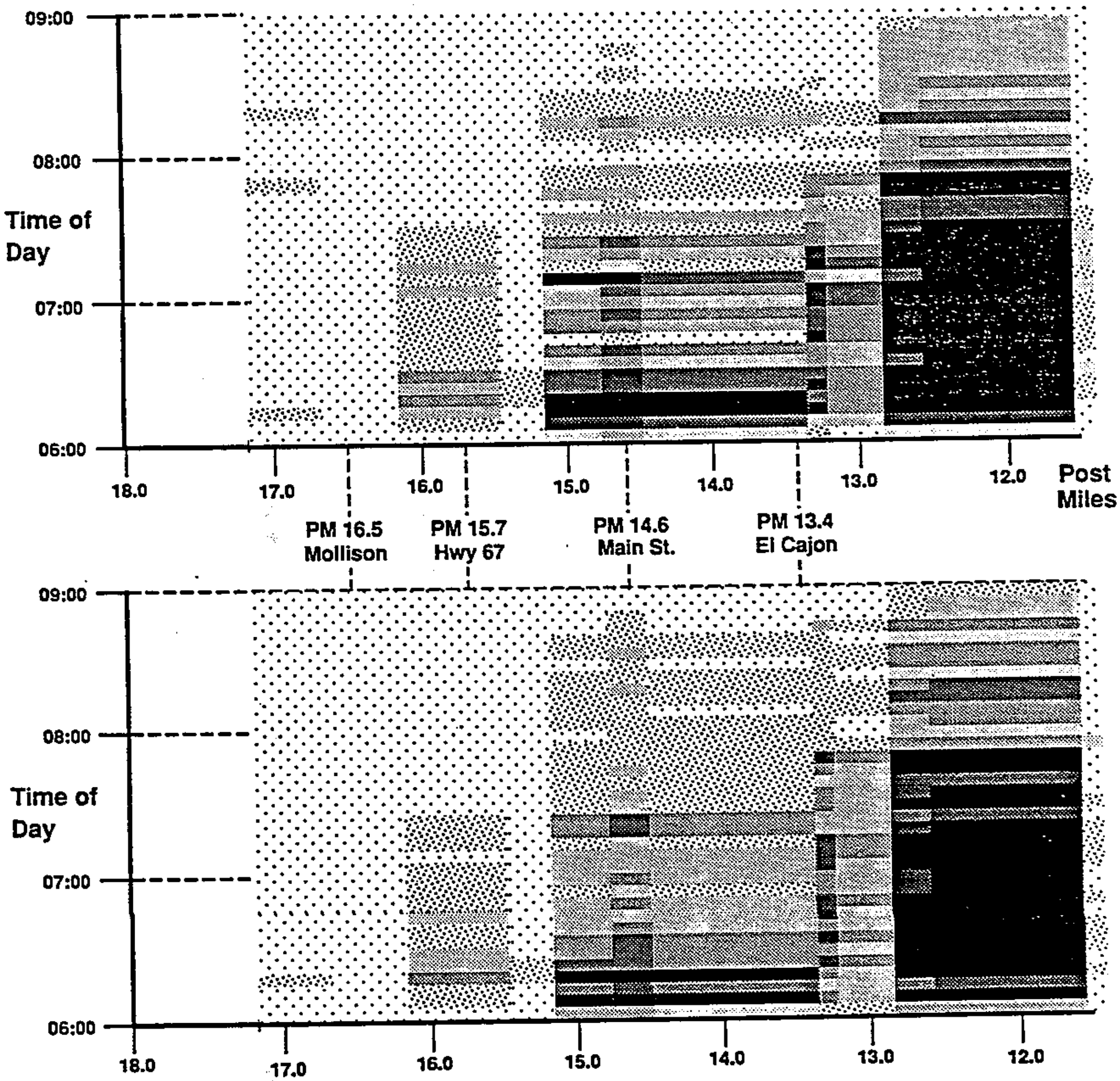


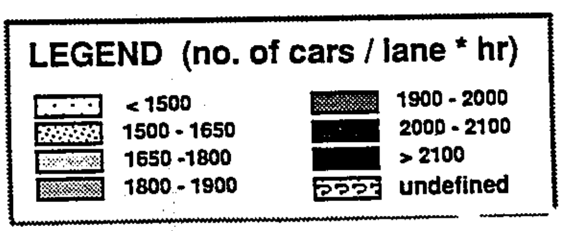
Volume Density Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/11/85 - Upper Plot 04/12/85 - Lower Plot





Direction of travel ---->>

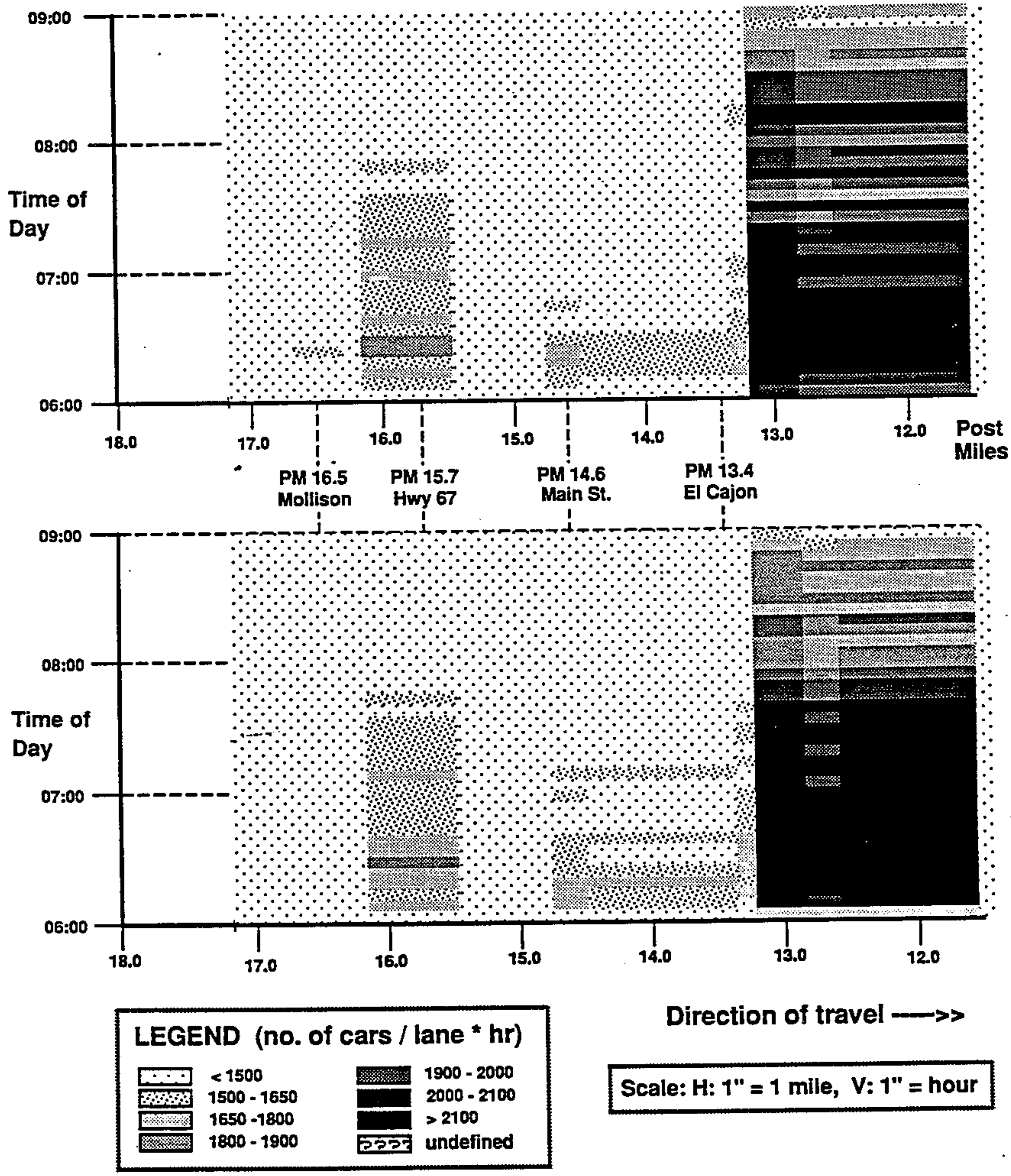
Scale: H: 1" = 1 mile, V: 1" = hour

Volume Density Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/15/85 - Upper Plot   04/16/85 - Lower Plot

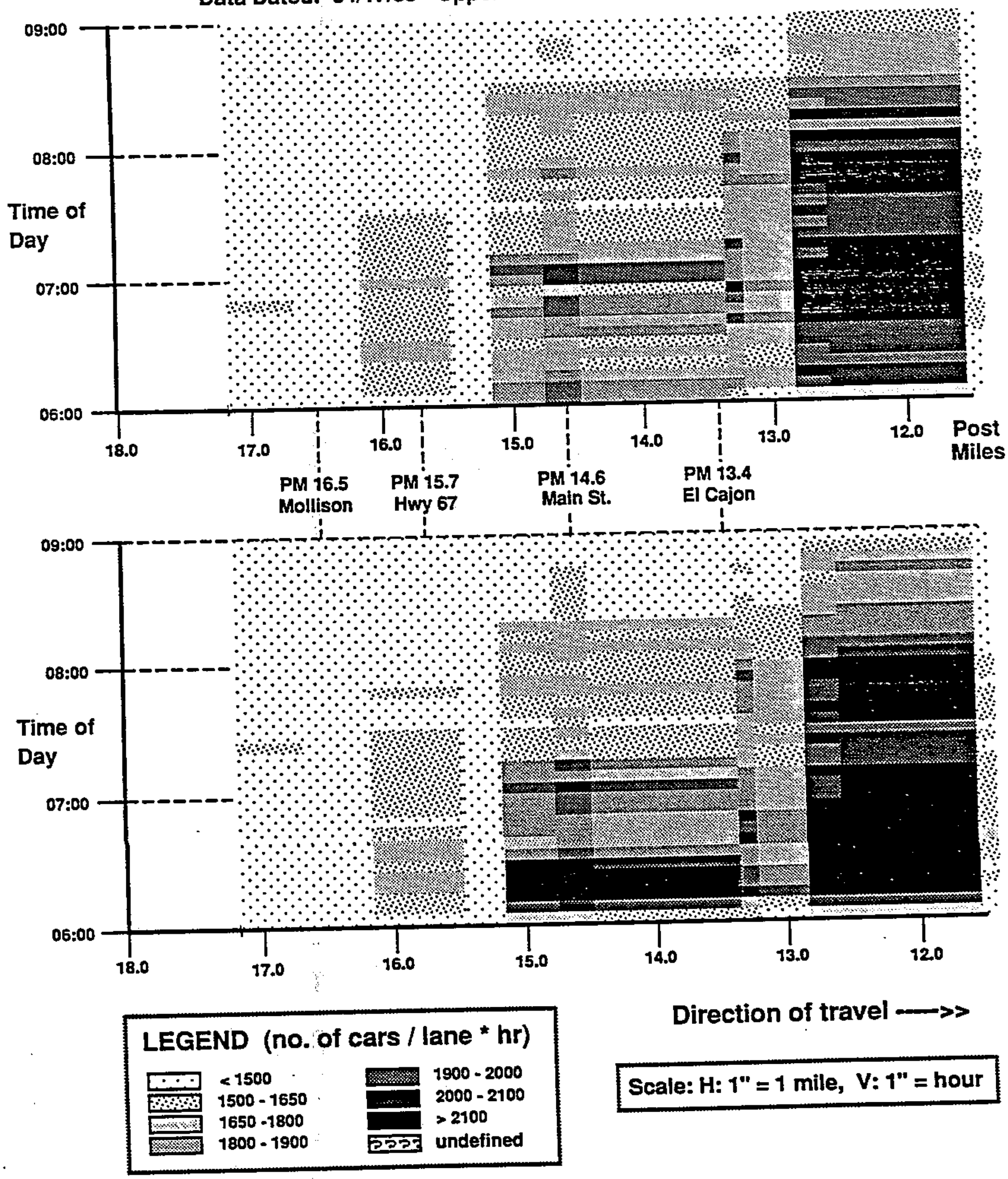


Volume Density Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/17/85 - Upper Plot 04/18/85 - Lower Plot

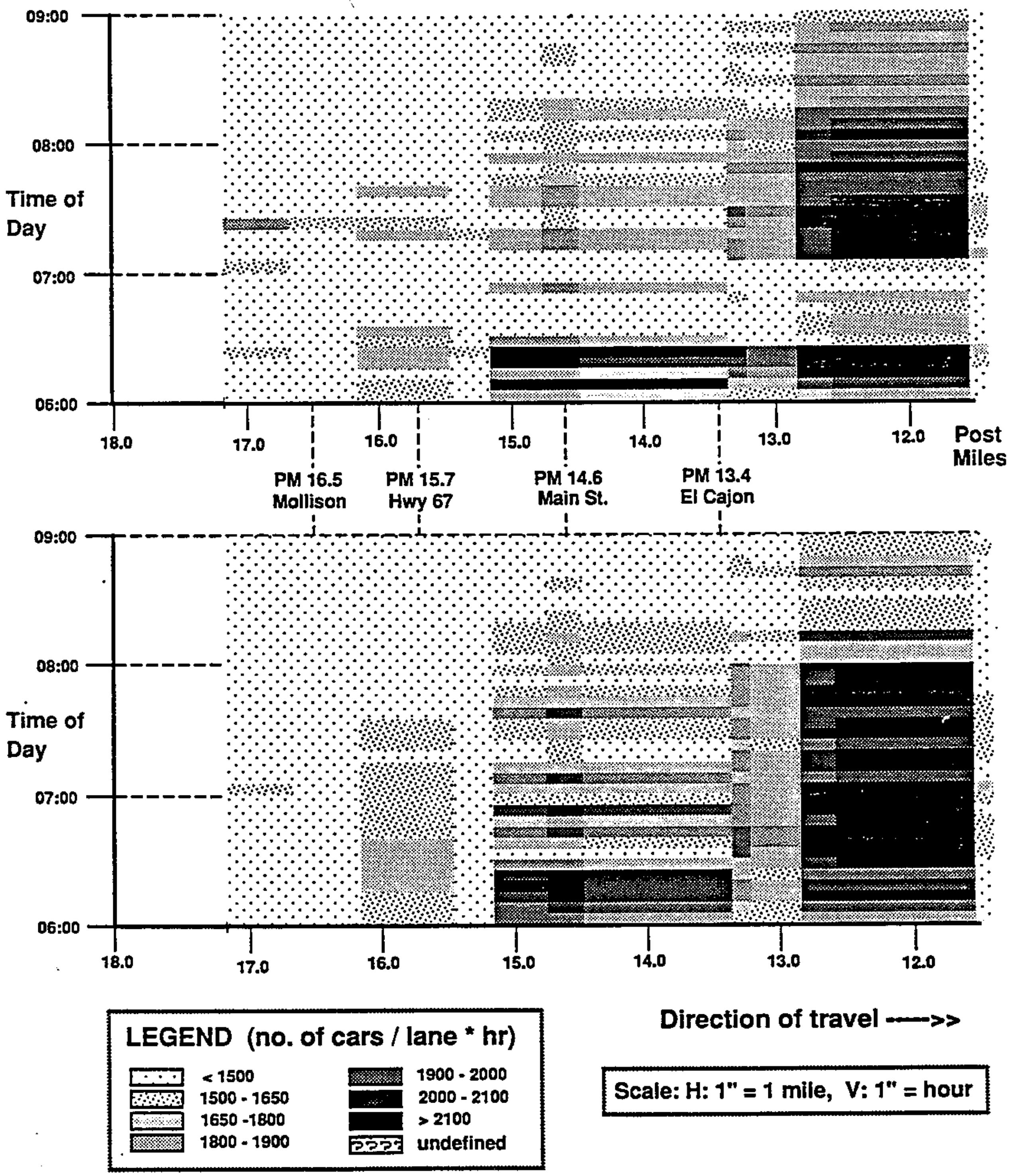


Volume Density Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/19/85 - Upper Plot 04/22/85 - Lower Plot

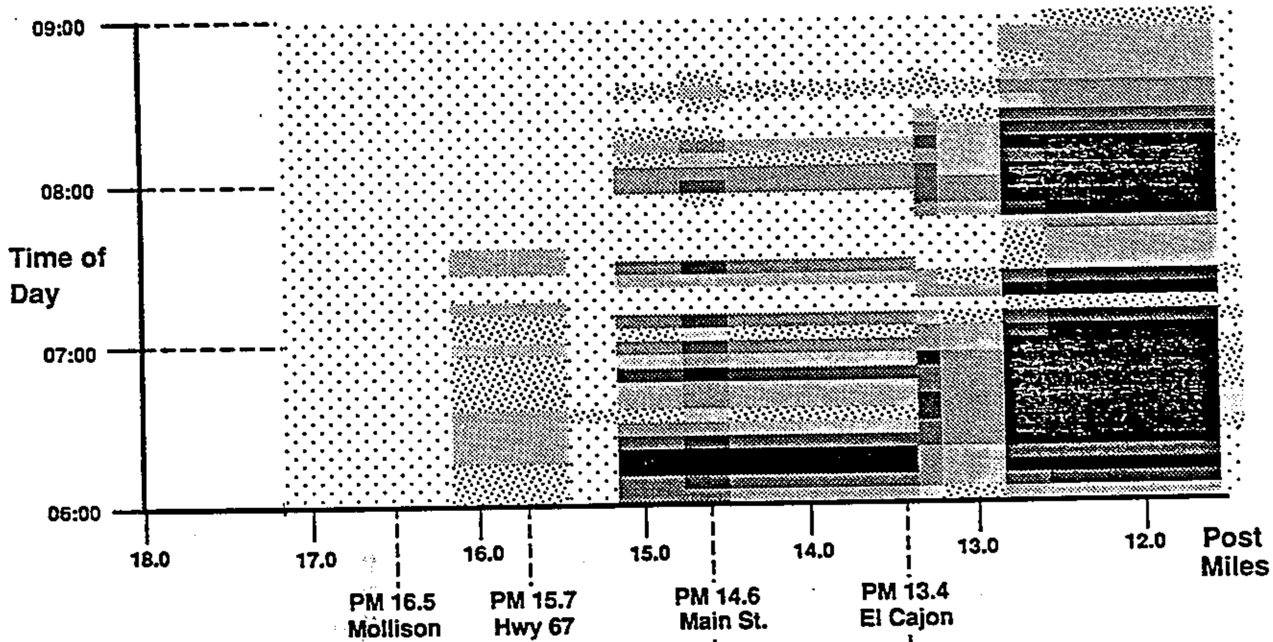


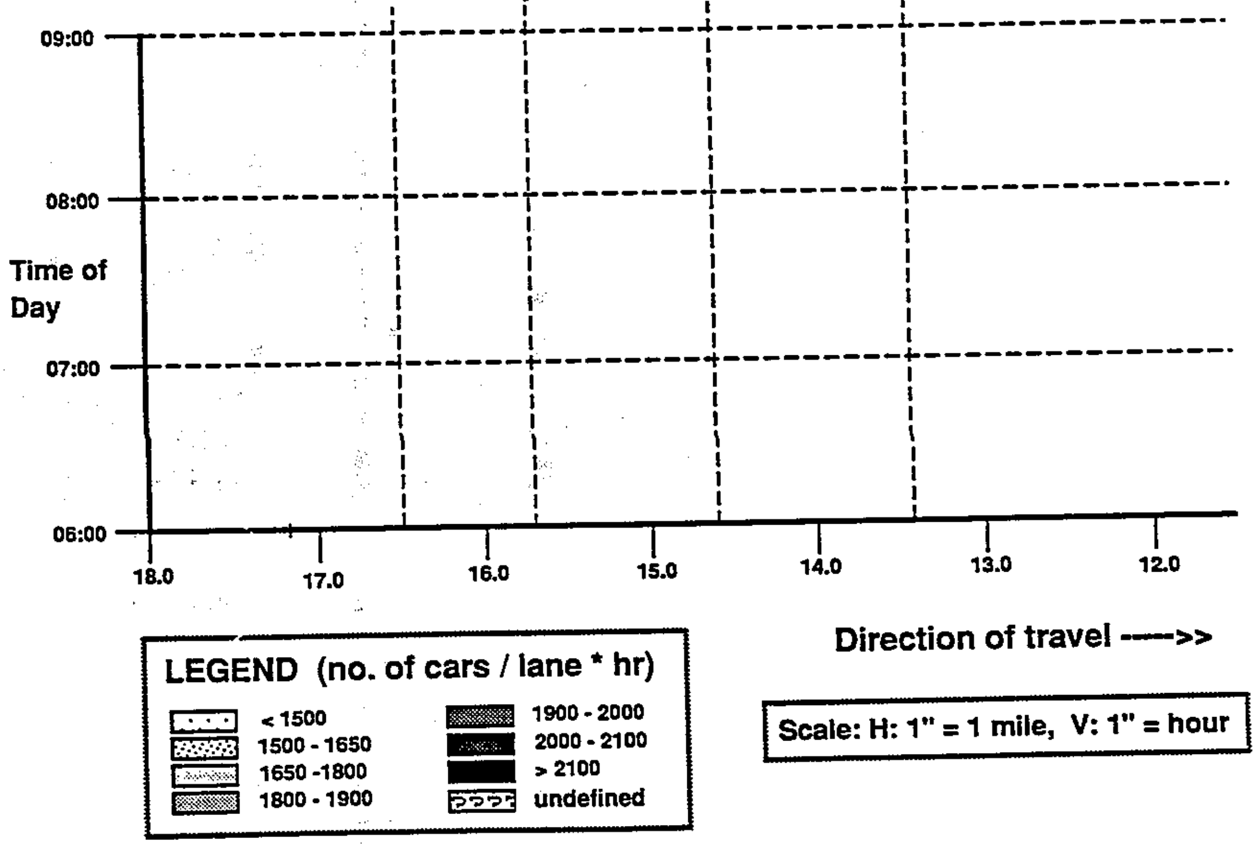
Volume Density Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/23/85 - Upper Plot   04/##/85 - Lower Plot



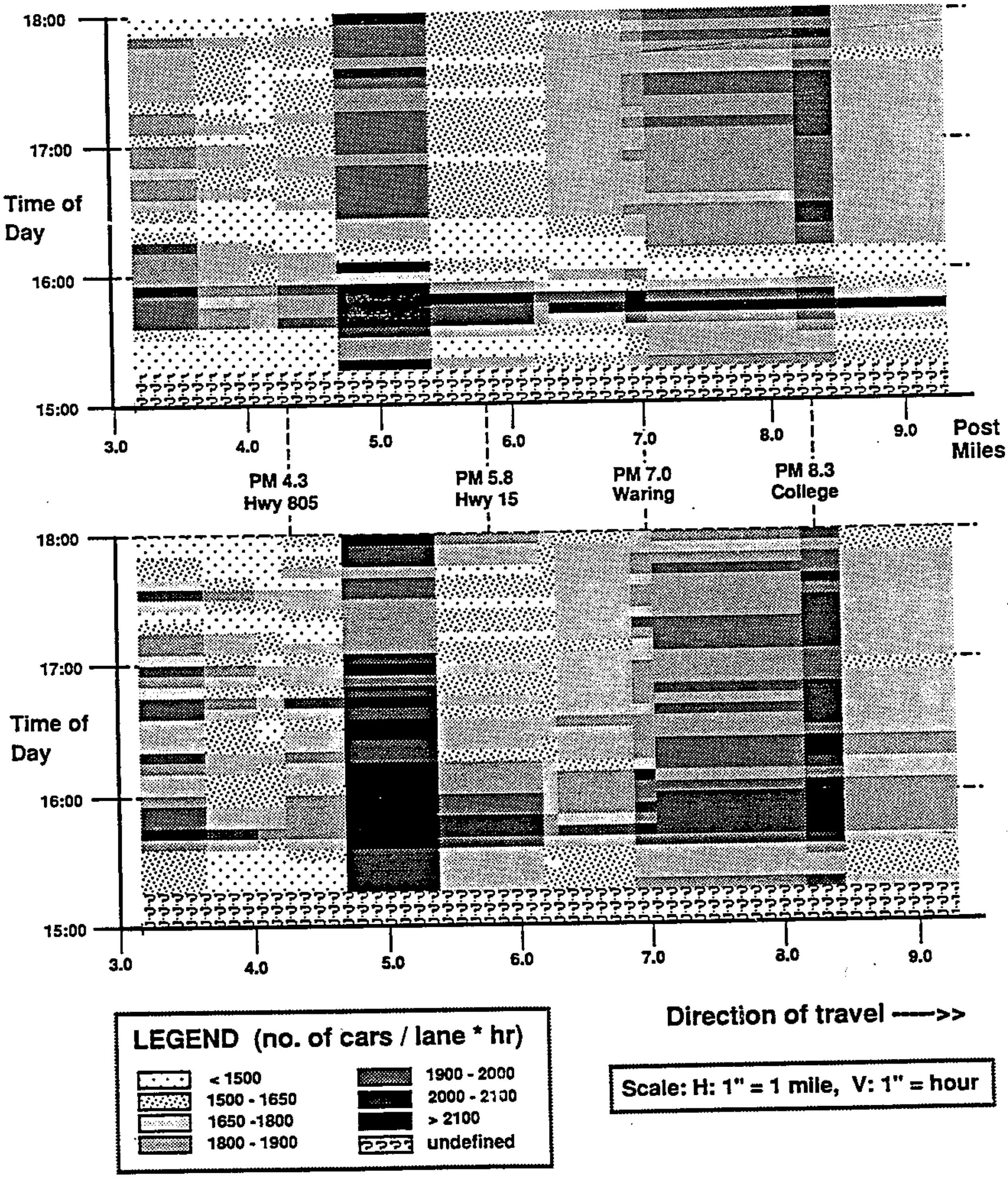


Volume Density Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/09/85 - Upper Plot 04/10/85 - Lower Plot

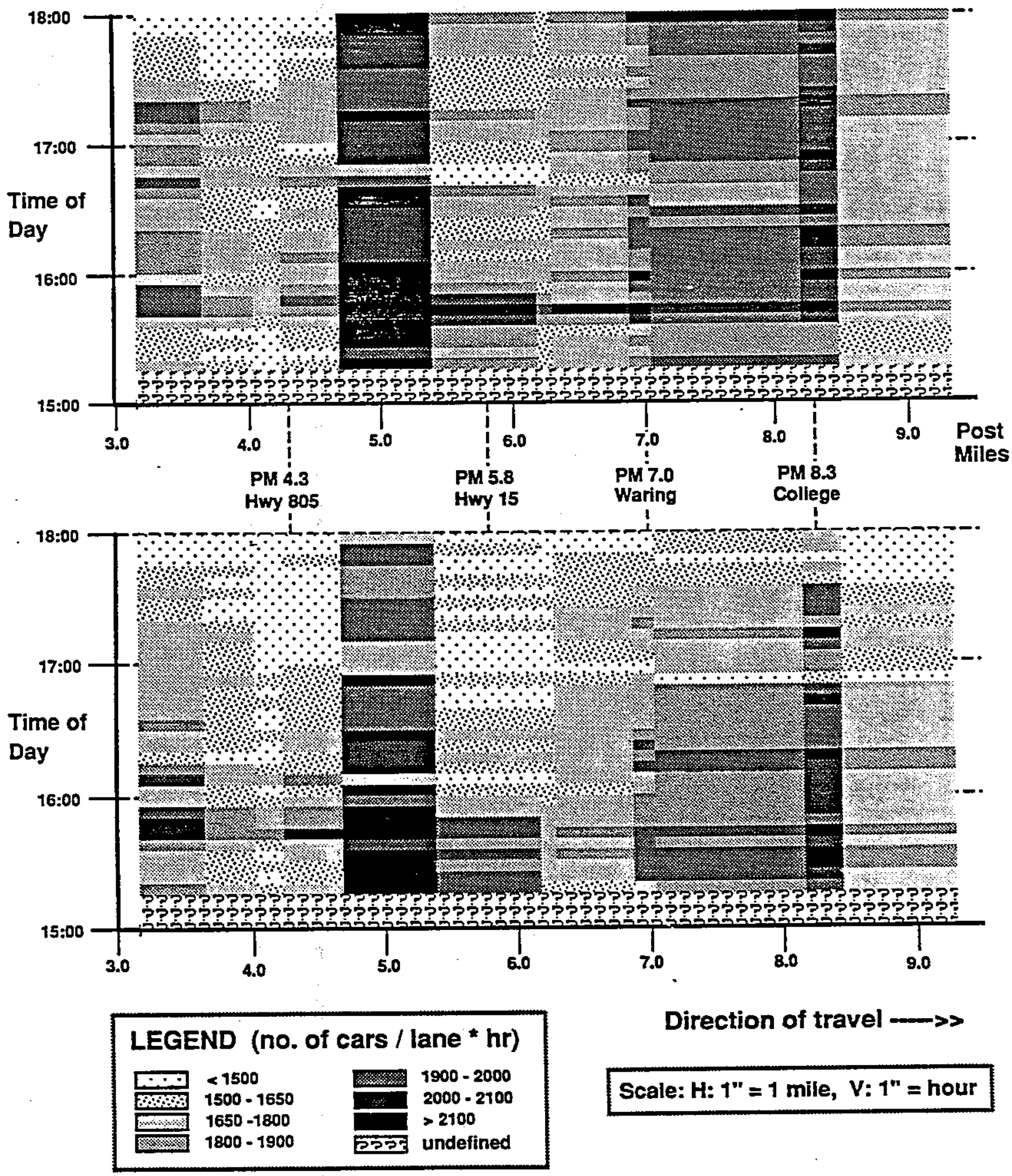


Volume Density Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/11/85 - Upper Plot 04/12/85 - Lower Plot

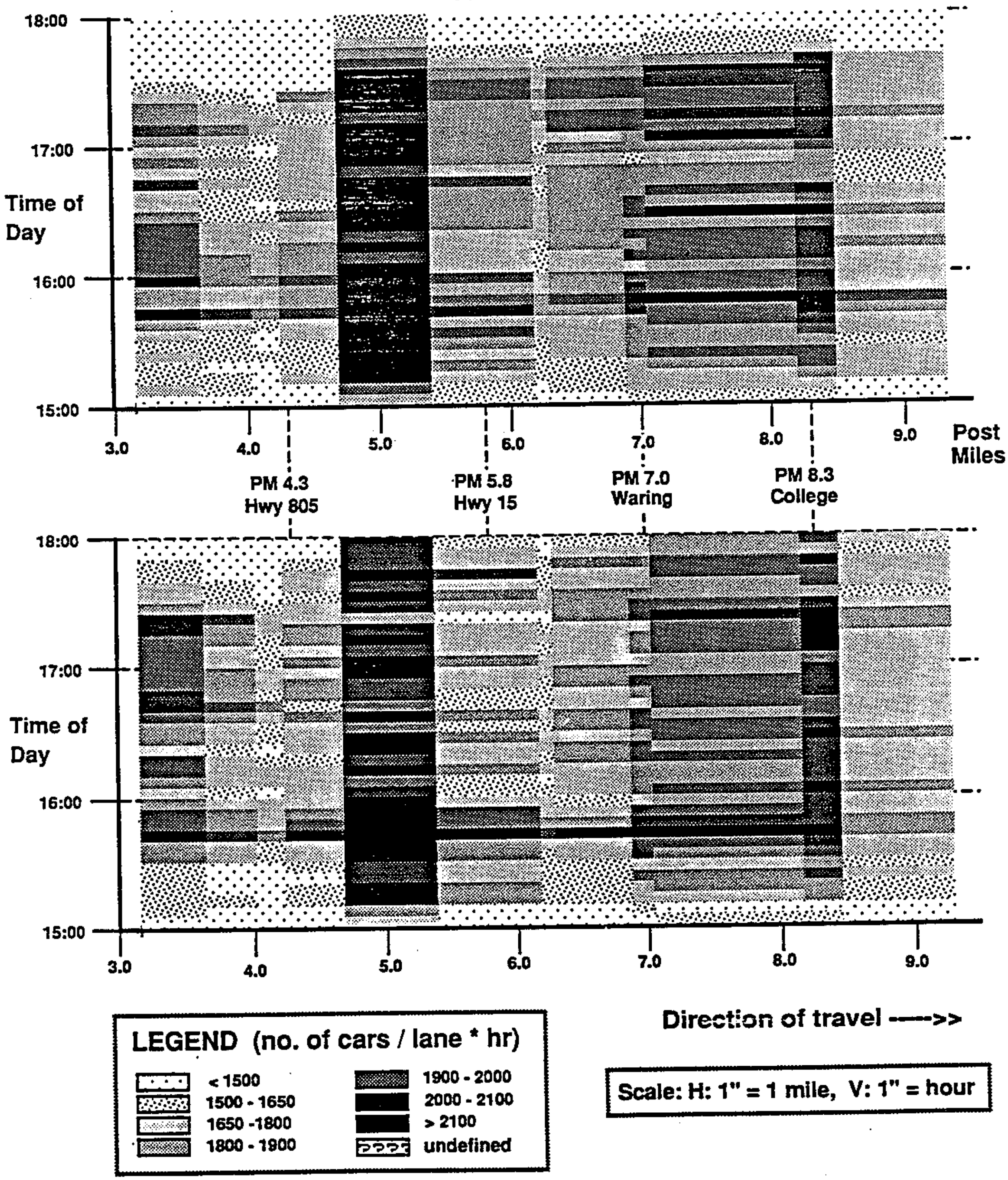


Volume Density Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/15/85 - Upper Plot 04/16/85 - Lower Plot

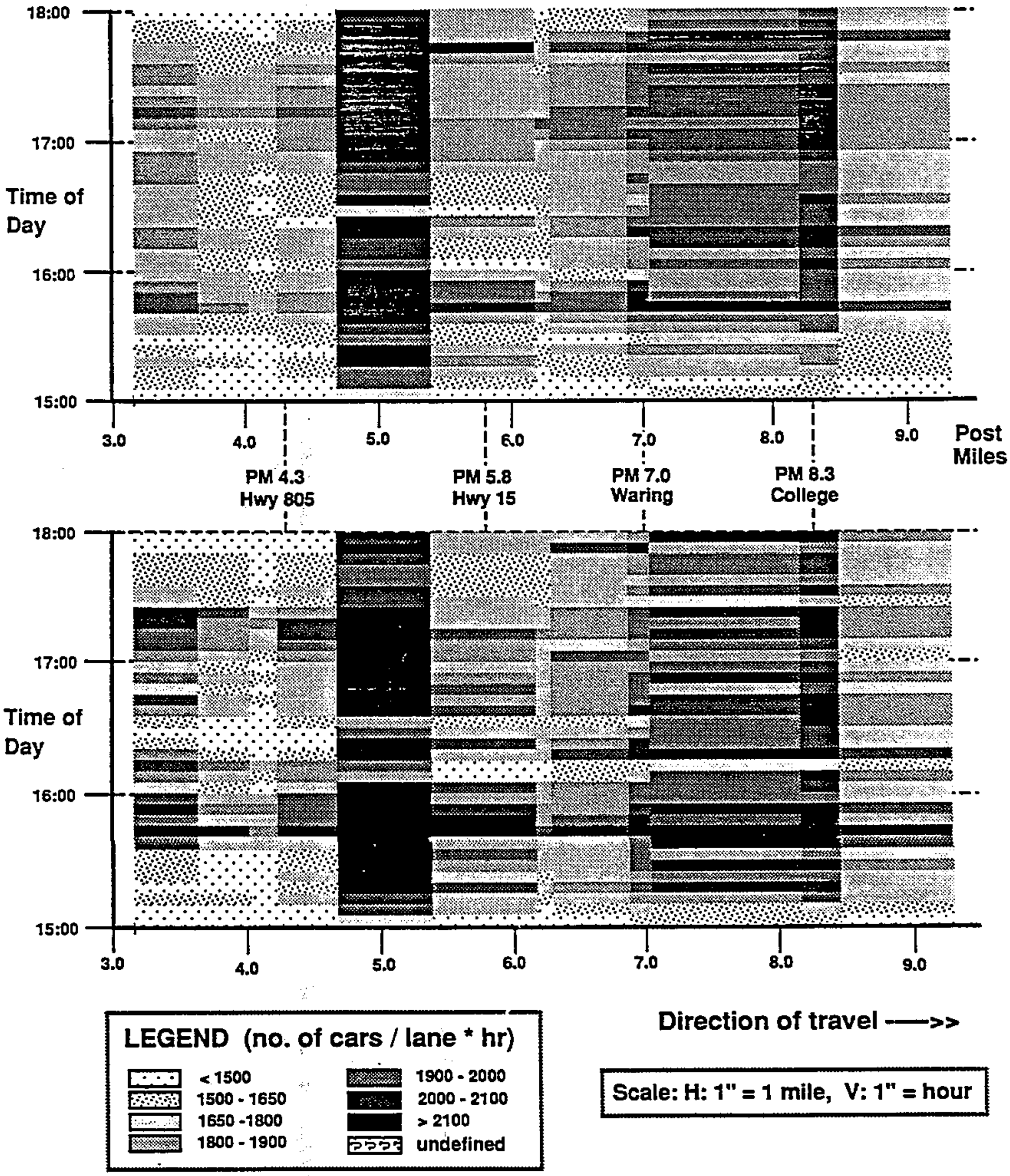


Volume Density Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/17/85 - Upper Plot 04/18/85 - Lower Plot

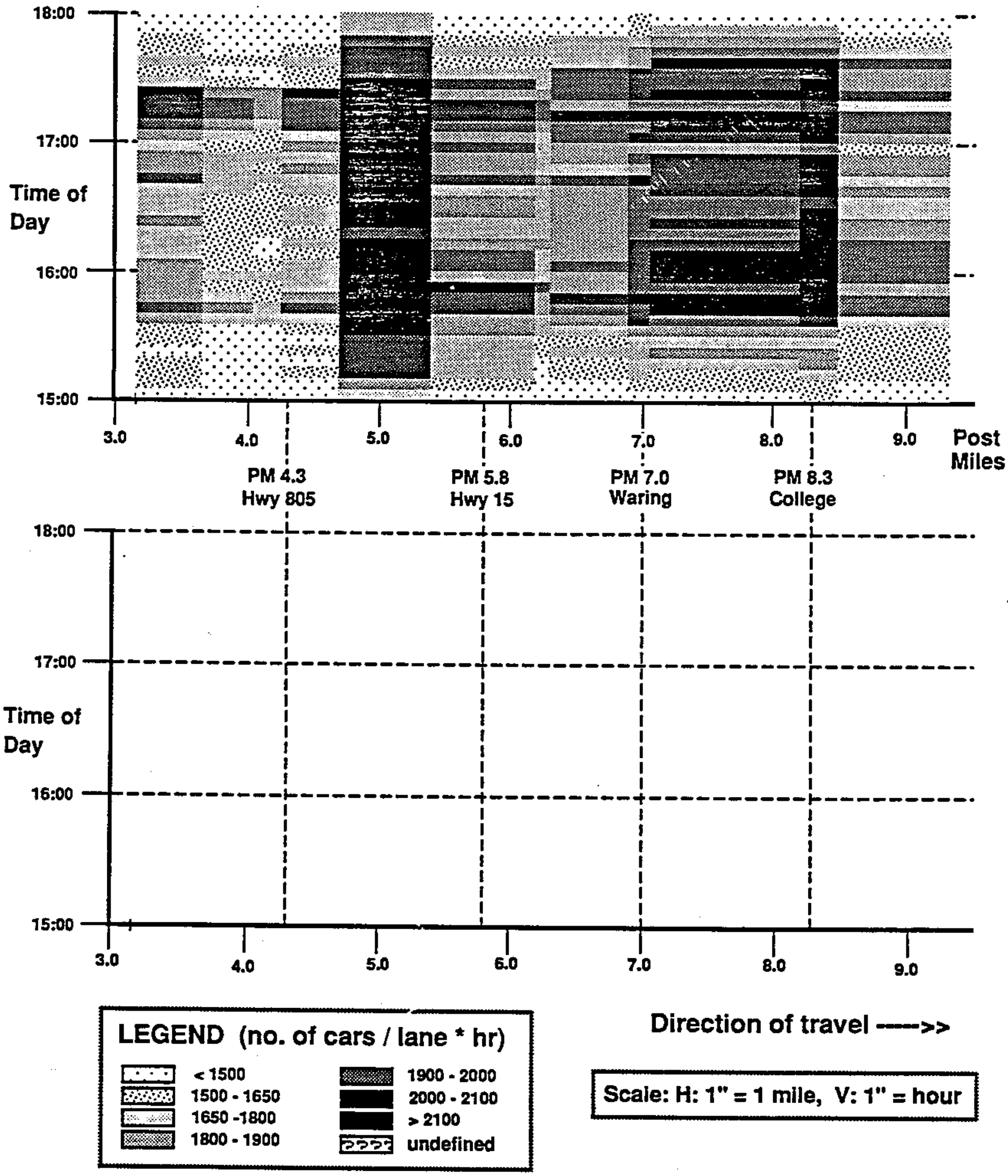


Volume Density Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/22/85 - Upper Plot ##/##/## - Lower Plot

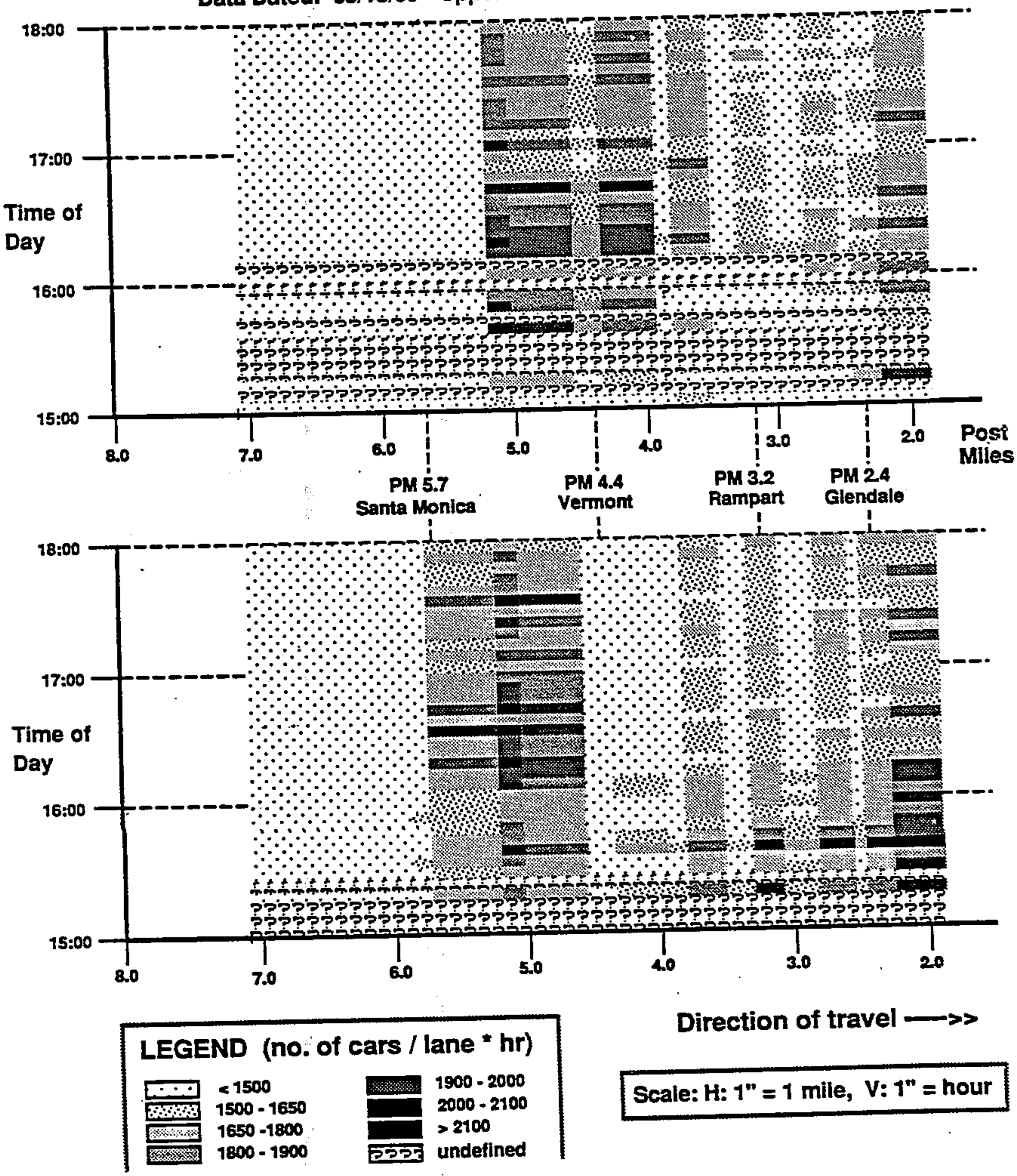


Volume Density Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/13/85 - Upper Plot 05/14/85 - Lower Plot

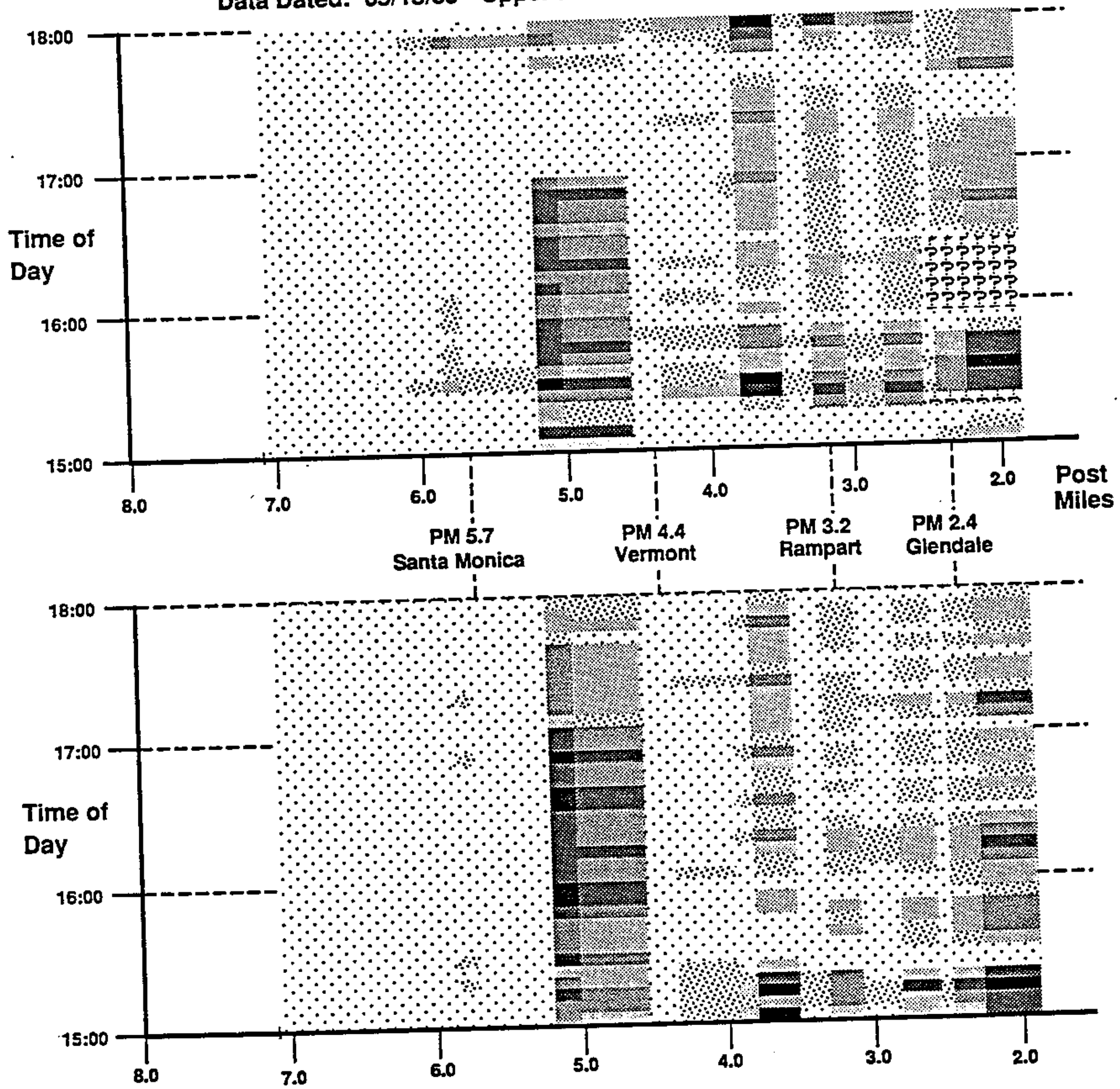


Volume Density Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/15/85 - Upper Plot 05/16/85 - Lower Plot



Direction of travel ---->>

LEGEND (no. of cars / lane * hr)

- < 1500
- 1500 - 1650
- 1650 -1800
- 1800 - 1900
- 1900 - 2000
- 2000 - 2100
- > 2100
- undefined

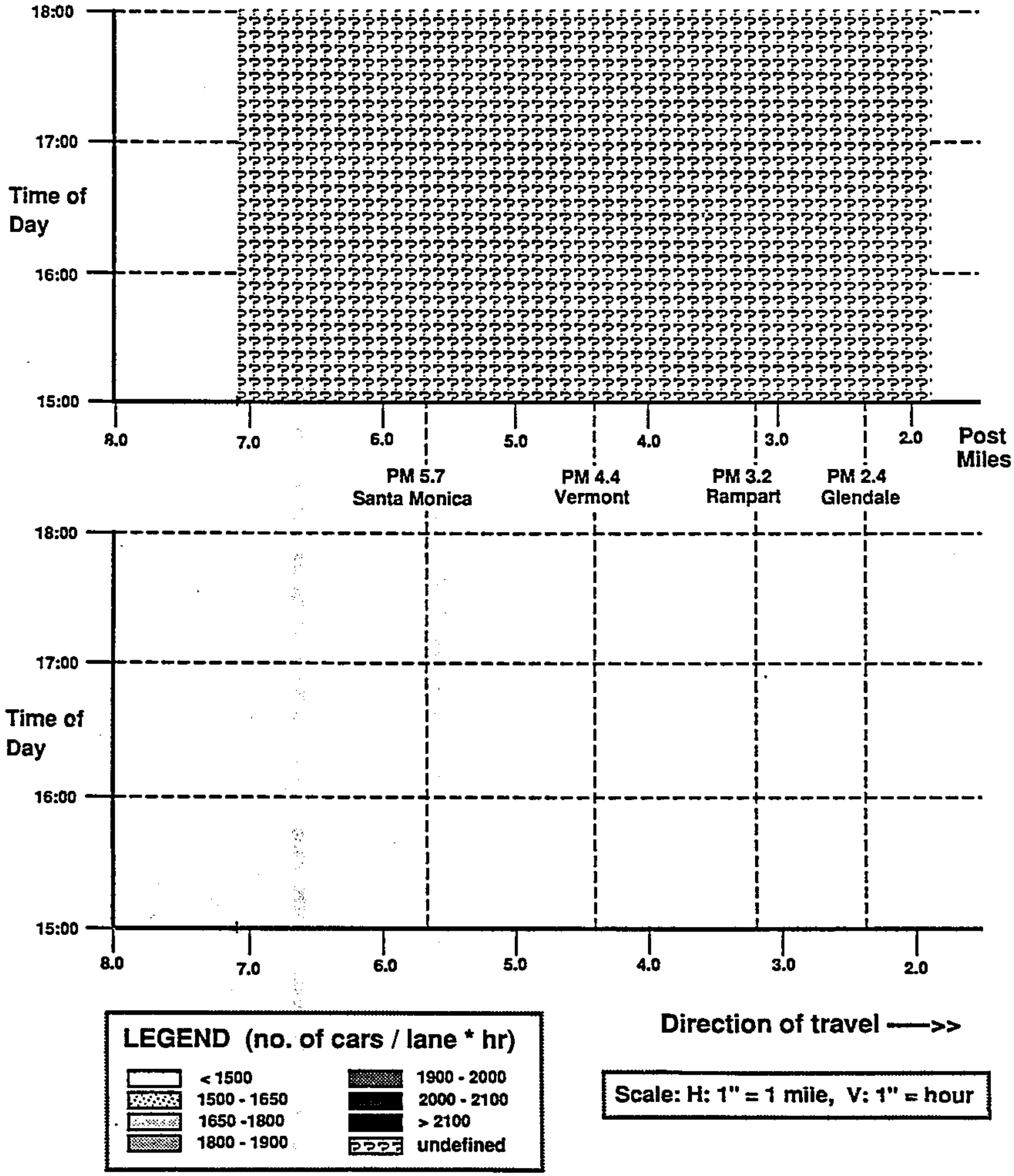
Scale: H: 1" = 1 mile, V: 1" = hour

Volume Density Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/17/85 - Upper Plot ##/##/## - Lower Plot

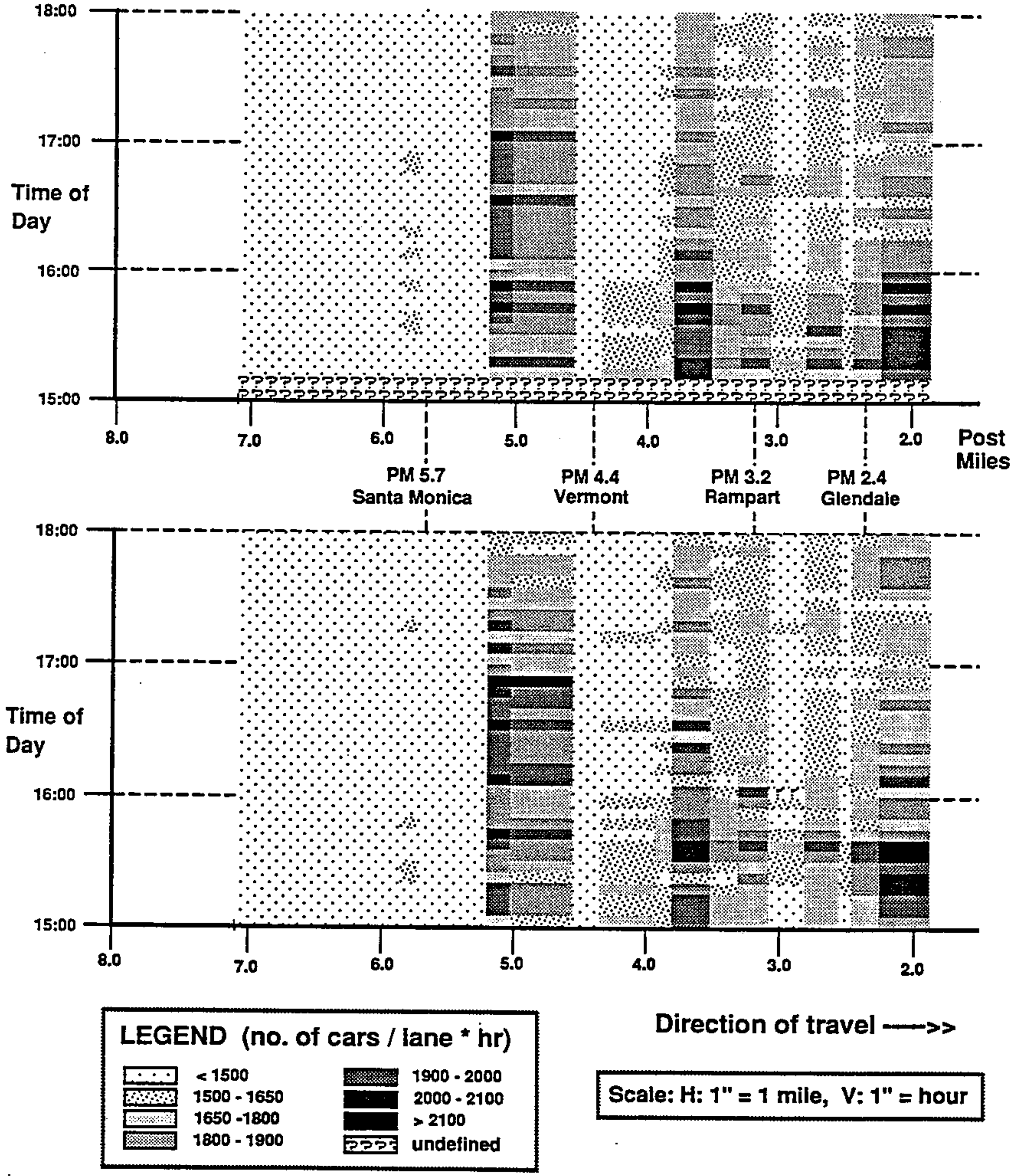


Volume Density Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/20/85 - Upper Plot 05/21/85 - Lower Plot

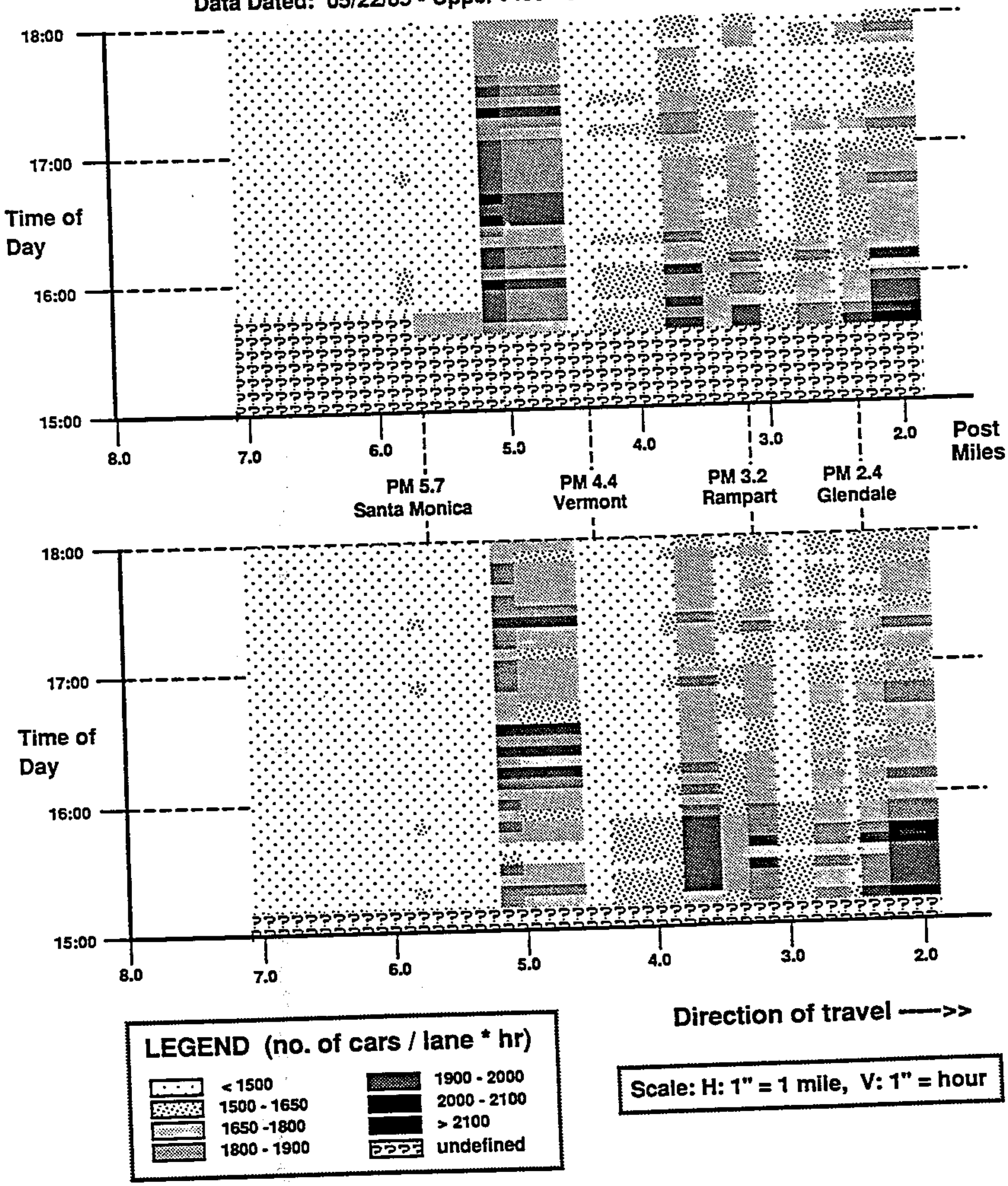


Volume Density Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/22/85 - Upper Plot 05/23/85 - Lower Plot

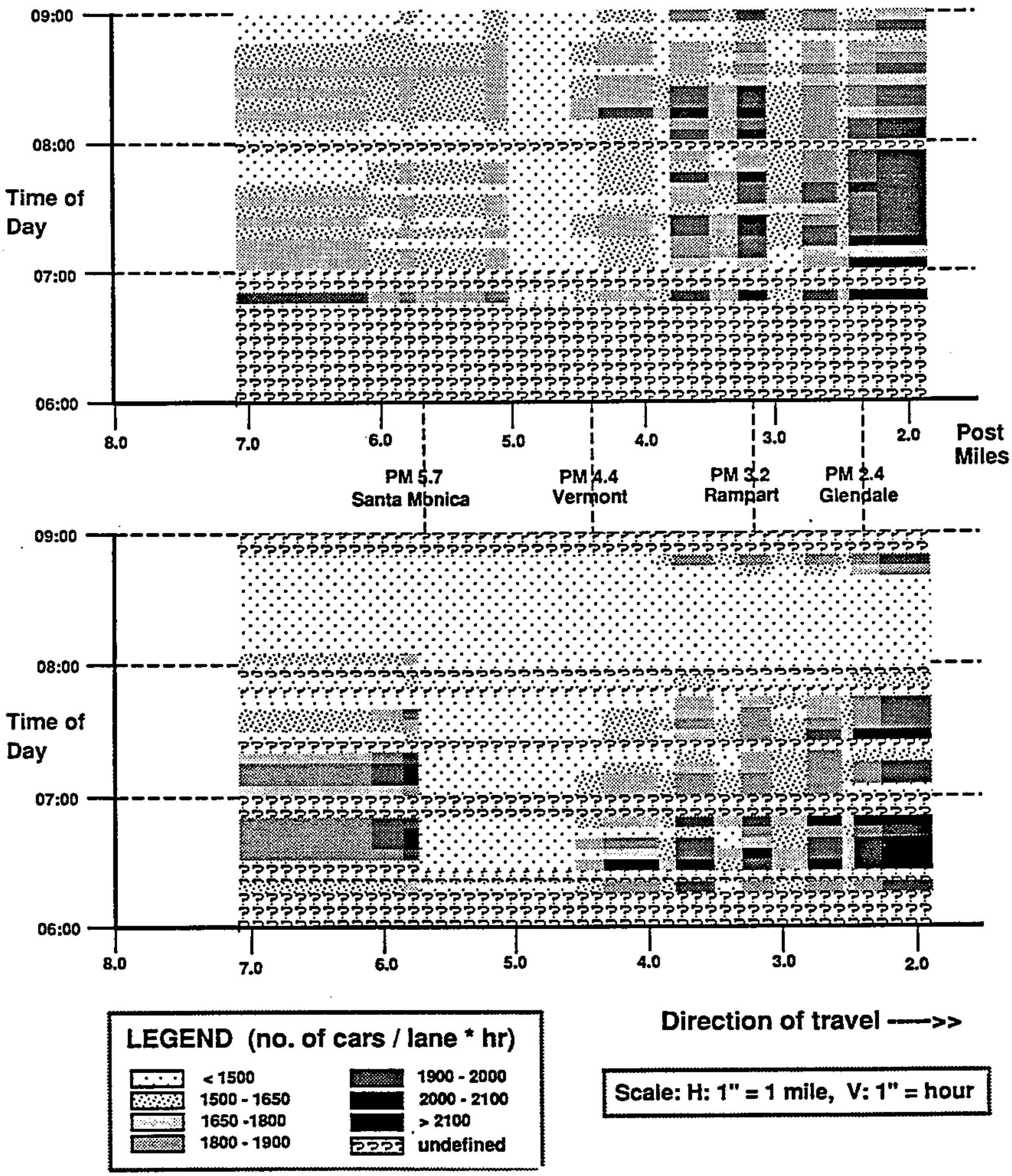


Volume Density Plots

Southbound Hwy 101, Los Angeles

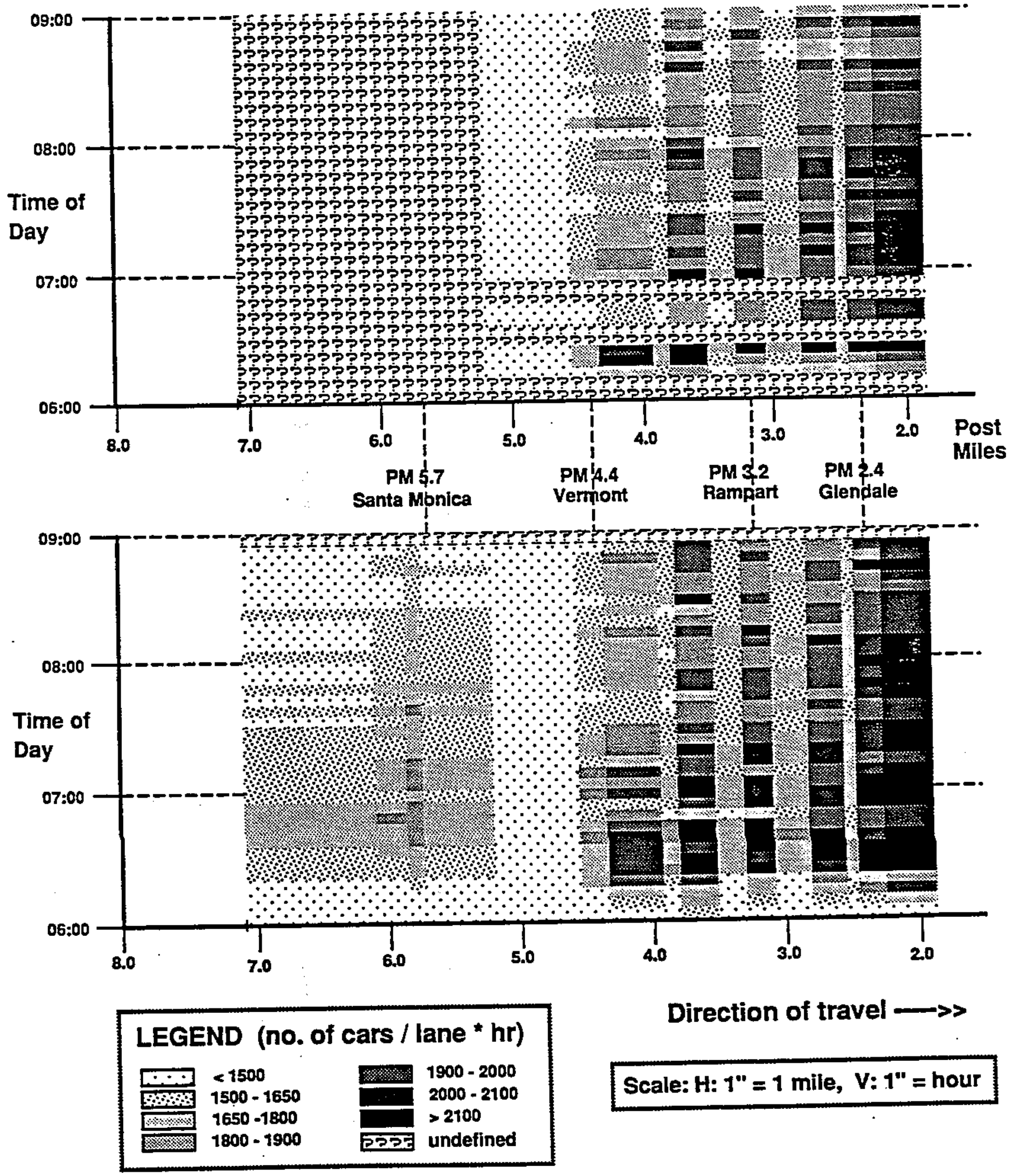
Morning

Data Dated: 05/13/85 - Upper Plot 05/14/85 - Lower Plot



Volume Density Plots

Southbound Hwy 101, Los Angeles
Morning
Data Dated: 05/15/85 - Upper Plot 05/16/85 - Lower Plot

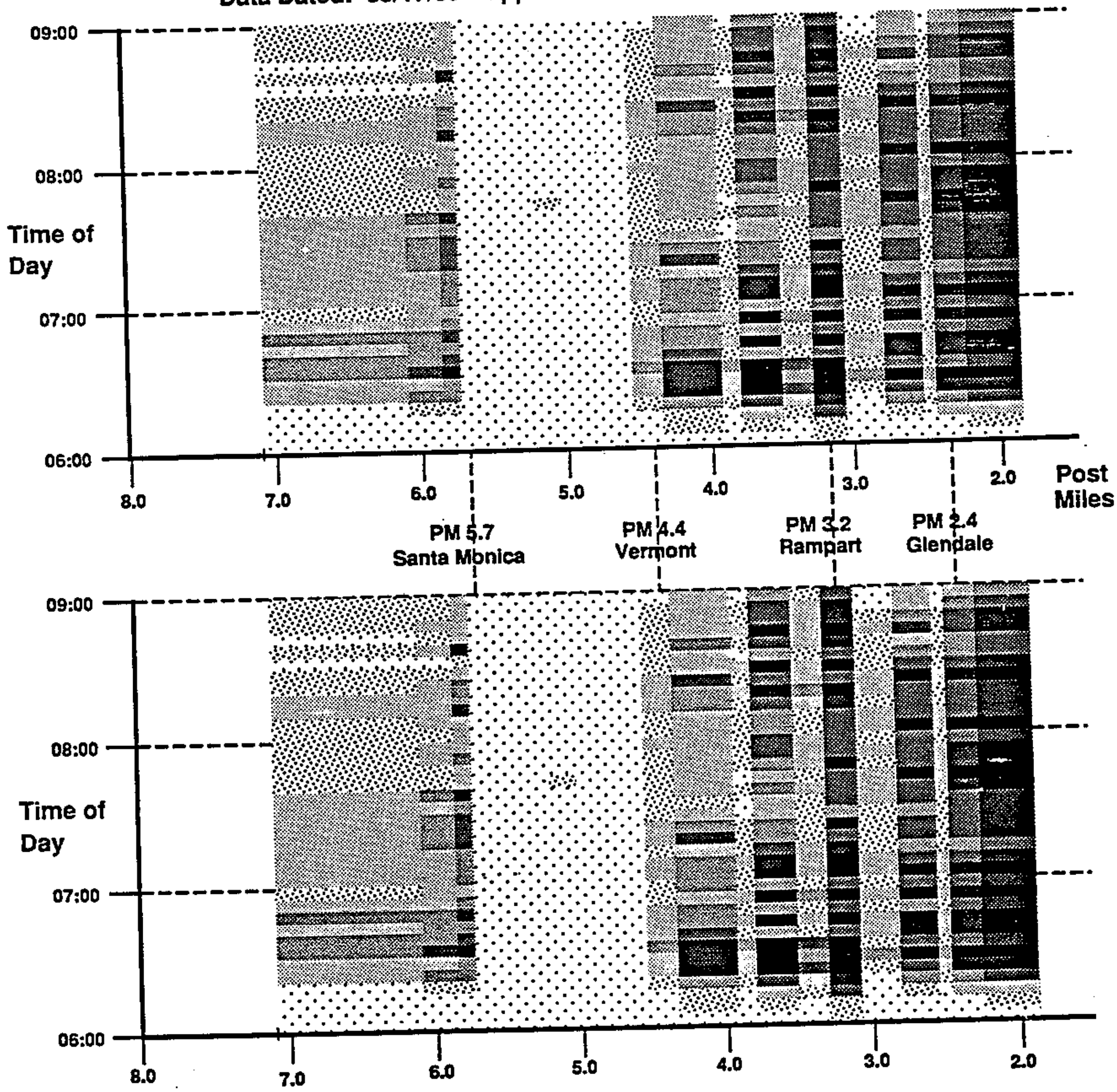


Volume Density Plots

Southbound Hwy 101, Los Angeles

Morning

Data Dated: 05/17/85 - Upper Plot ##/##/## - Lower Plot



Direction of travel ---->>

LEGEND (no. of cars / lane * hr)

- < 1500
- 1500 - 1650
- 1650 -1800
- 1800 - 1900
- 1900 - 2000
- 2000 - 2100
- > 2100
- undefined

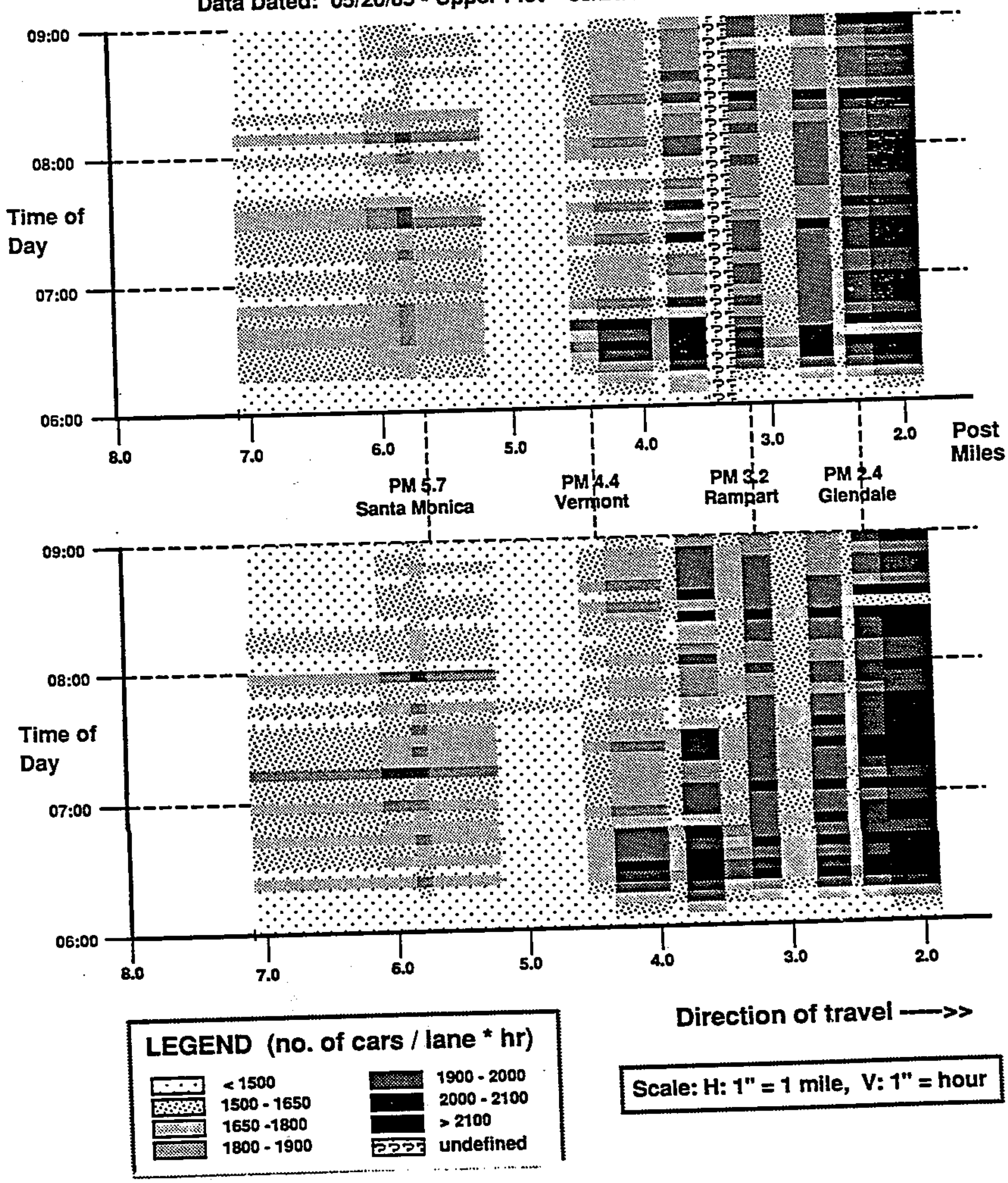
Scale: H: 1" = 1 mile, V: 1" = hour

Volume Density Plots

Southbound Hwy 101, Los Angeles

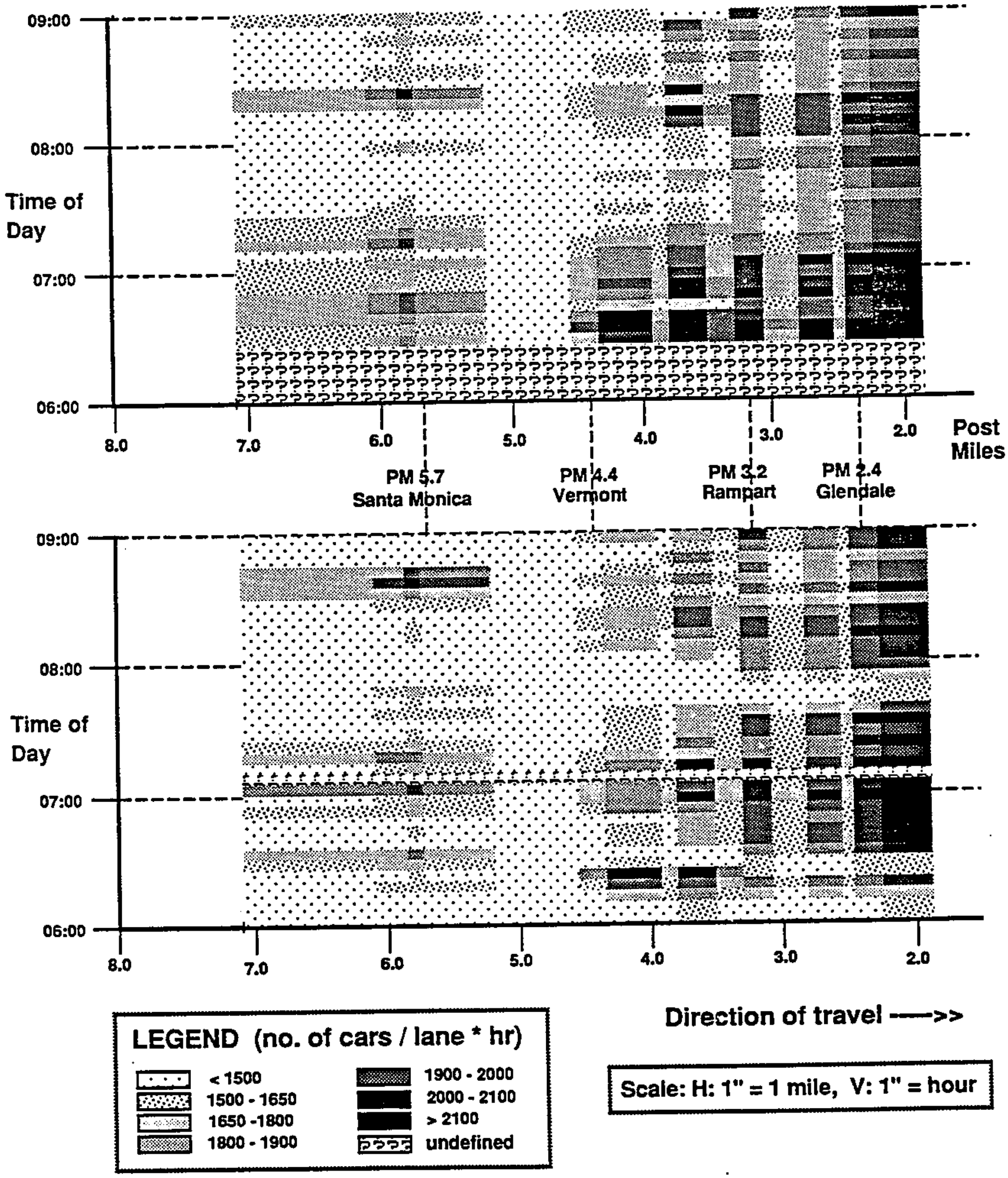
Morning

Data Dated: 05/20/85 - Upper Plot 05/21/85 - Lower Plot



Volume Density Plots

Southbound Hwy 101, Los Angeles
Morning
Data Dated: 05/22/85 - Upper Plot   05/23/85 - Lower Plot

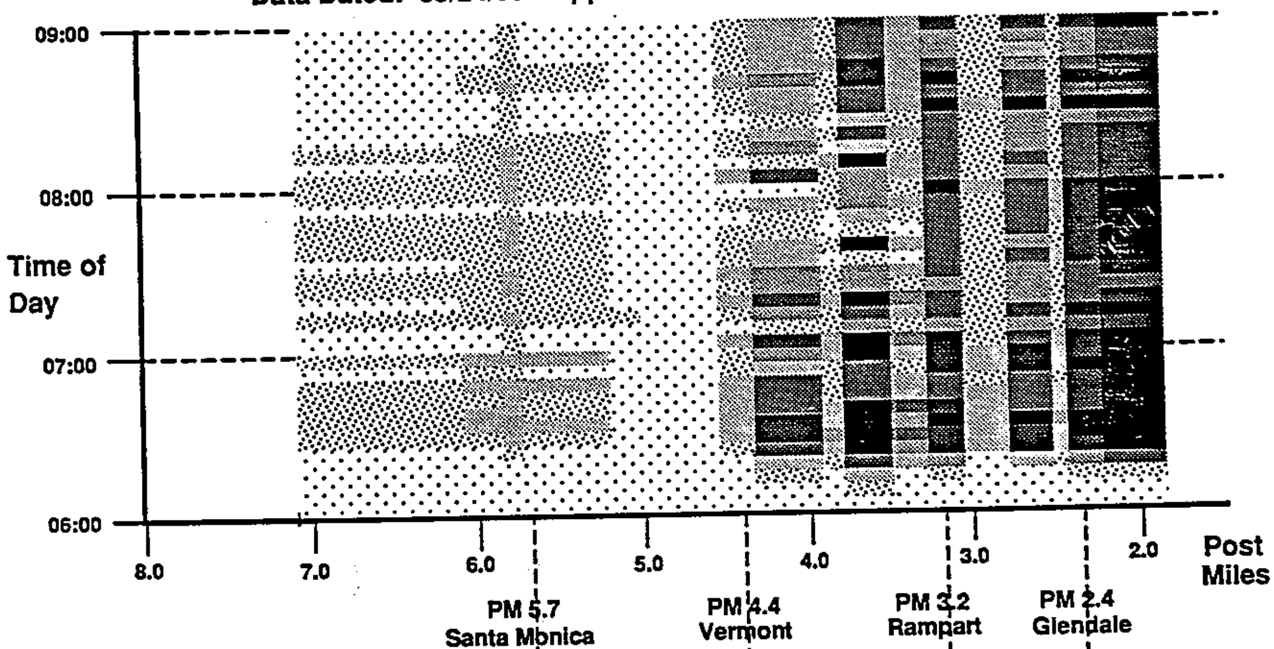


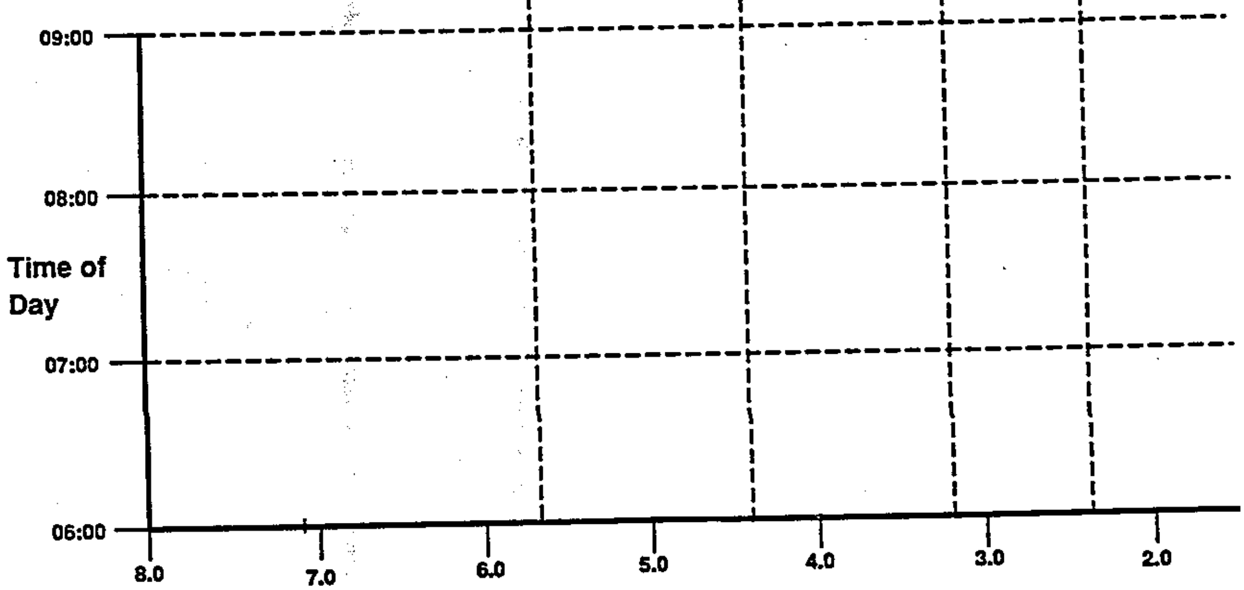
Volume Density Plots

Southbound Hwy 101, Los Angeles

Morning

Data Dated: 05/24/85 - Upper Plot ##/##/## - Lower Plot





Direction of travel ---->>

LEGEND (no. of cars / lane * hr)

< 1500	1900 - 2000
1500 - 1650	2000 - 2100
1650 -1800	> 2100
1800 - 1900	undefined

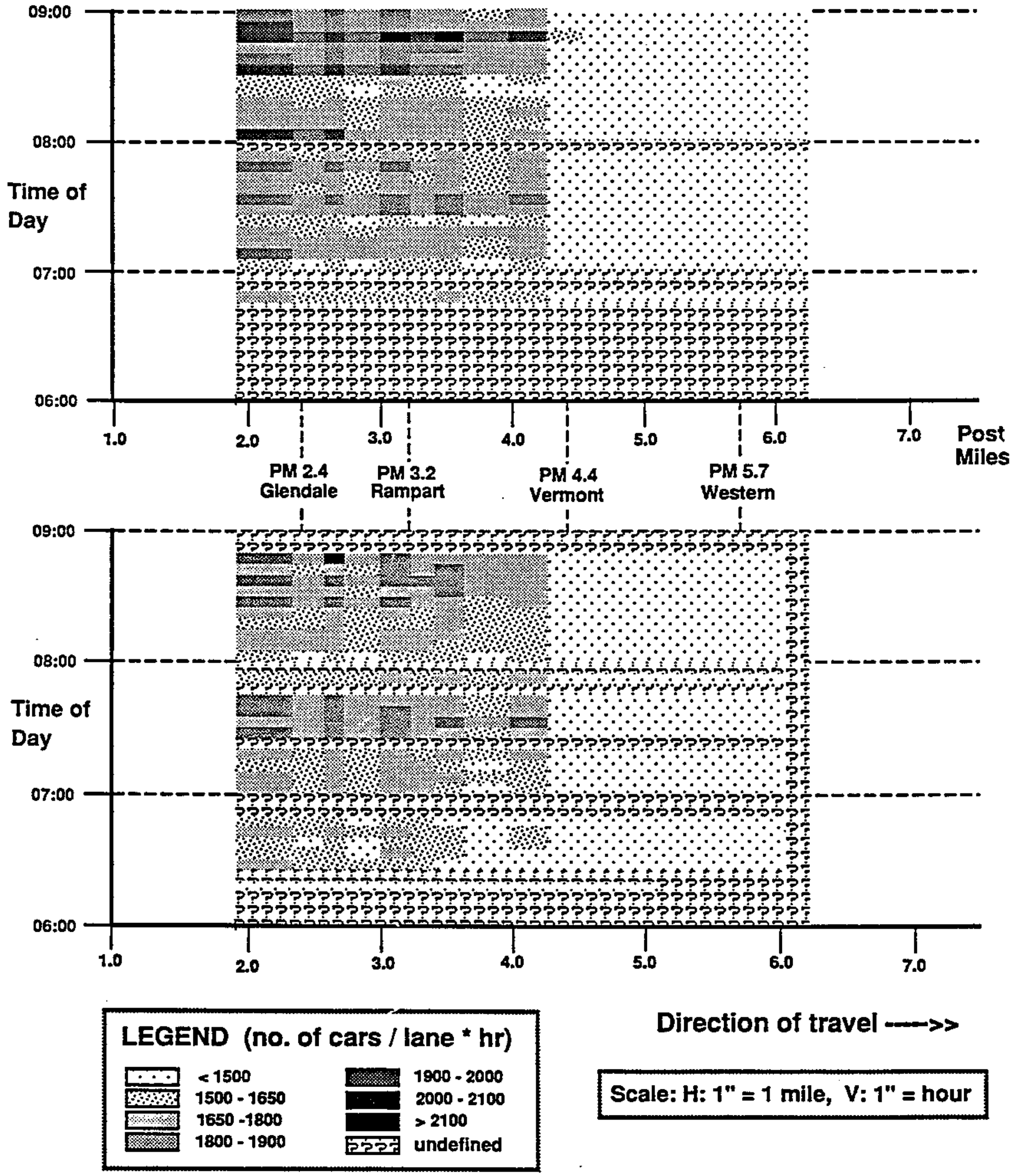
Scale: H: 1" = 1 mile, V: 1" = hour

Volume Density Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/13/85 - Upper Plot 05/14/85 - Lower Plot

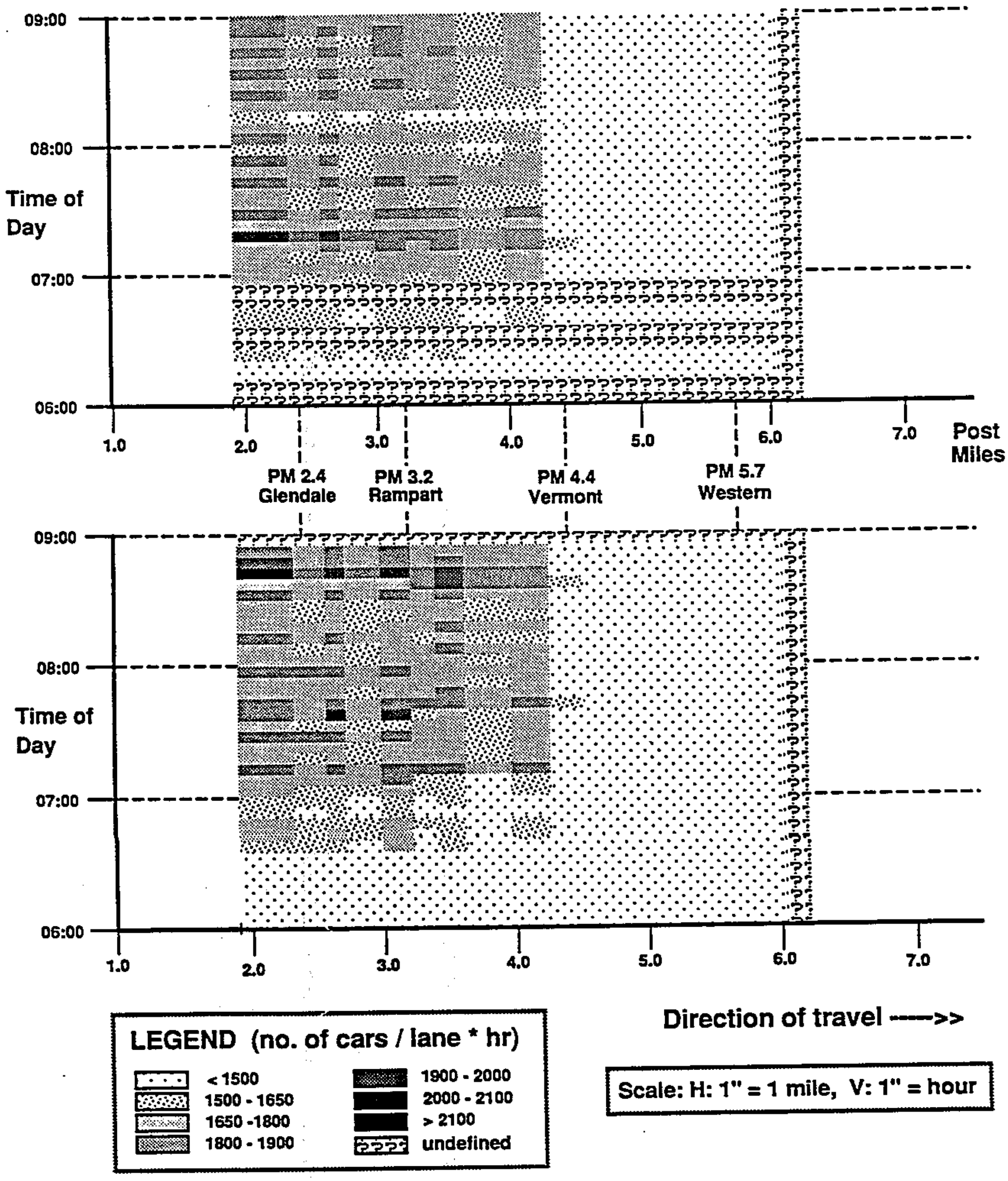


Volume Density Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/15/85 - Upper Plot 05/16/85 - Lower Plot

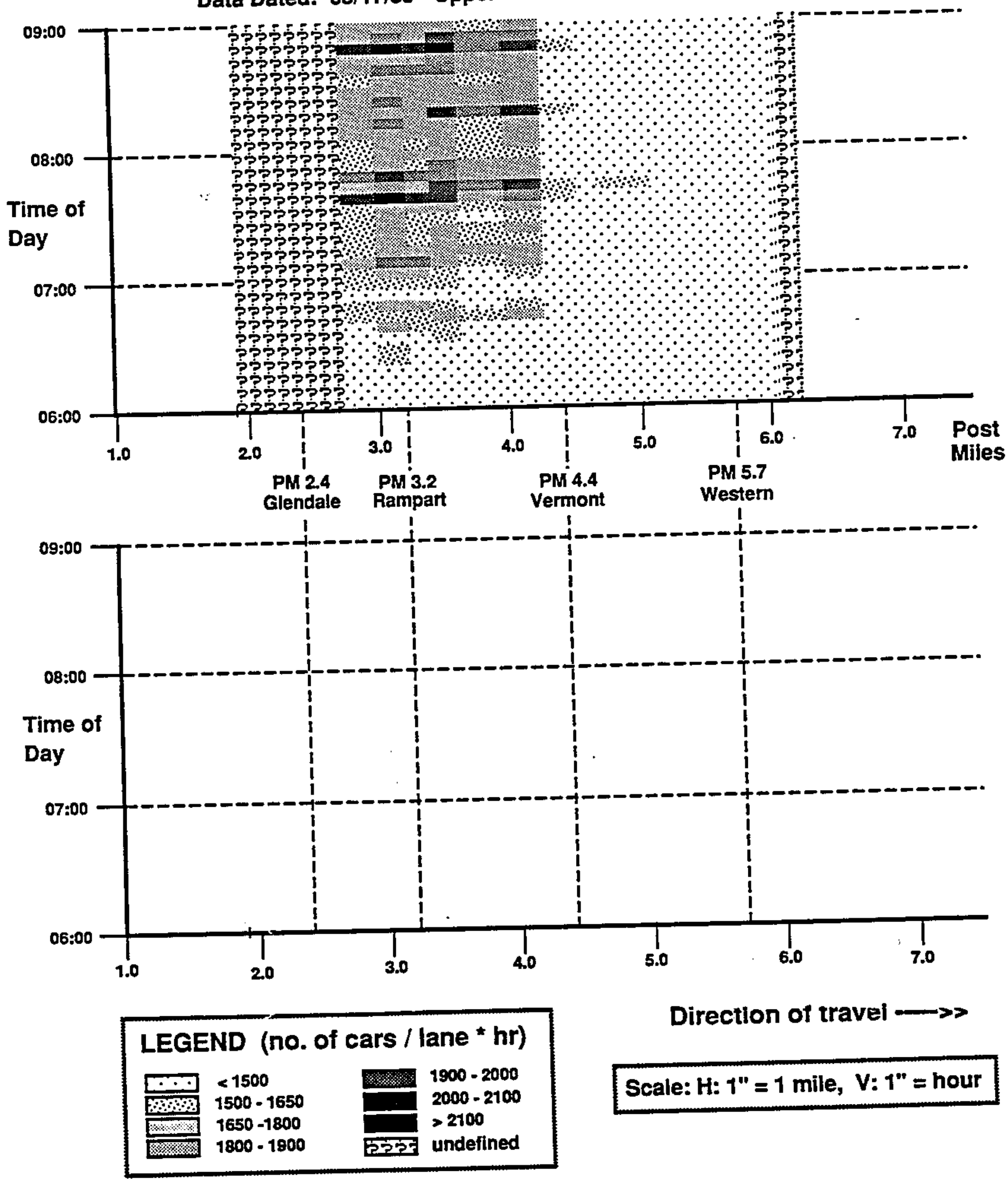


Volume Density Plots

Northbound Hwy 101, Los Angeles

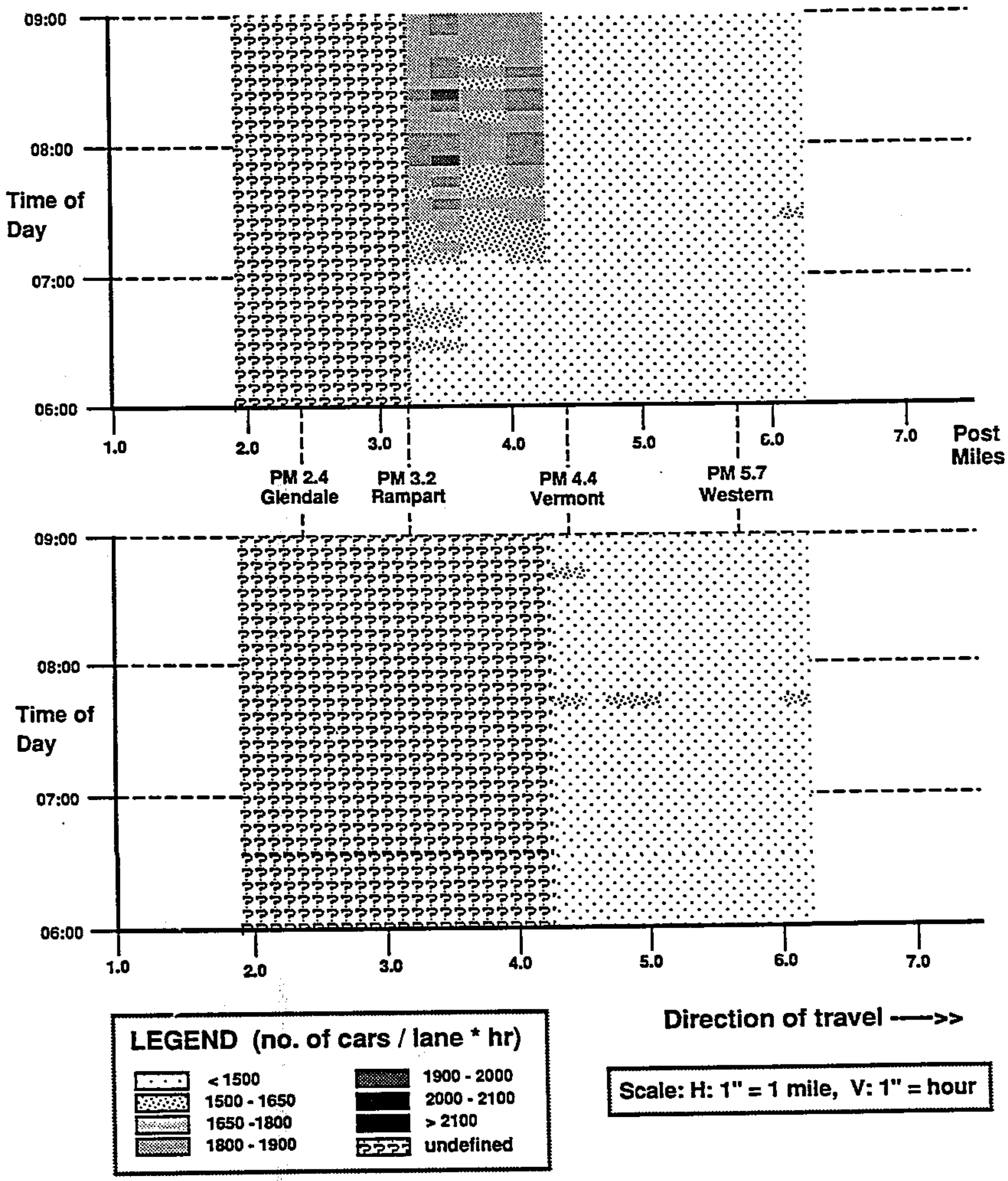
Morning

Data Dated: 05/17/85 - Upper Plot ##/##/## - Lower Plot



Volume Density Plots

Northbound Hwy 101, Los Angeles
Morning
Data Dated: 05/20/85 - Upper Plot 05/21/85 - Lower Plot

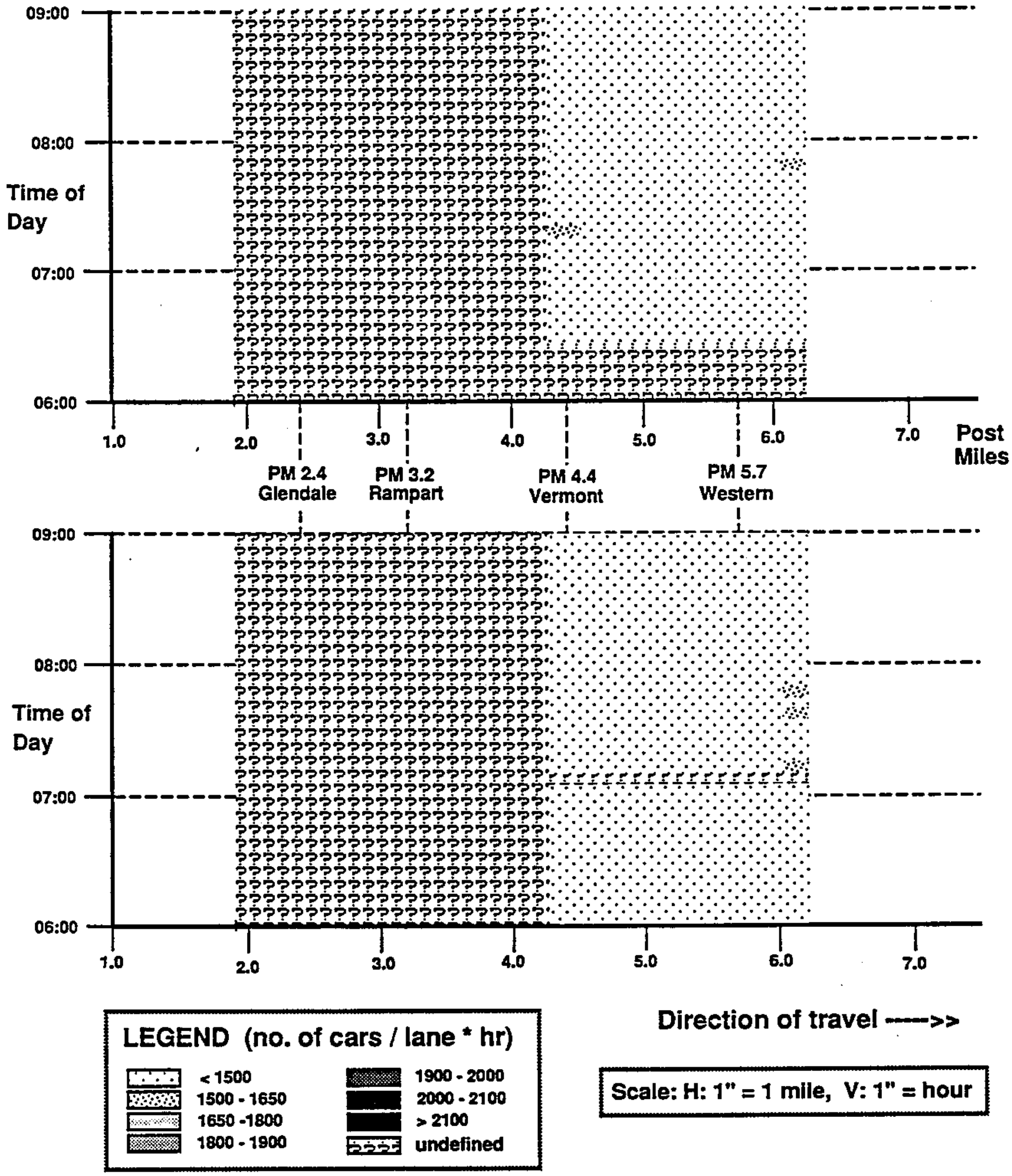


Volume Density Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/22/85 - Upper Plot 05/23/85 - Lower Plot

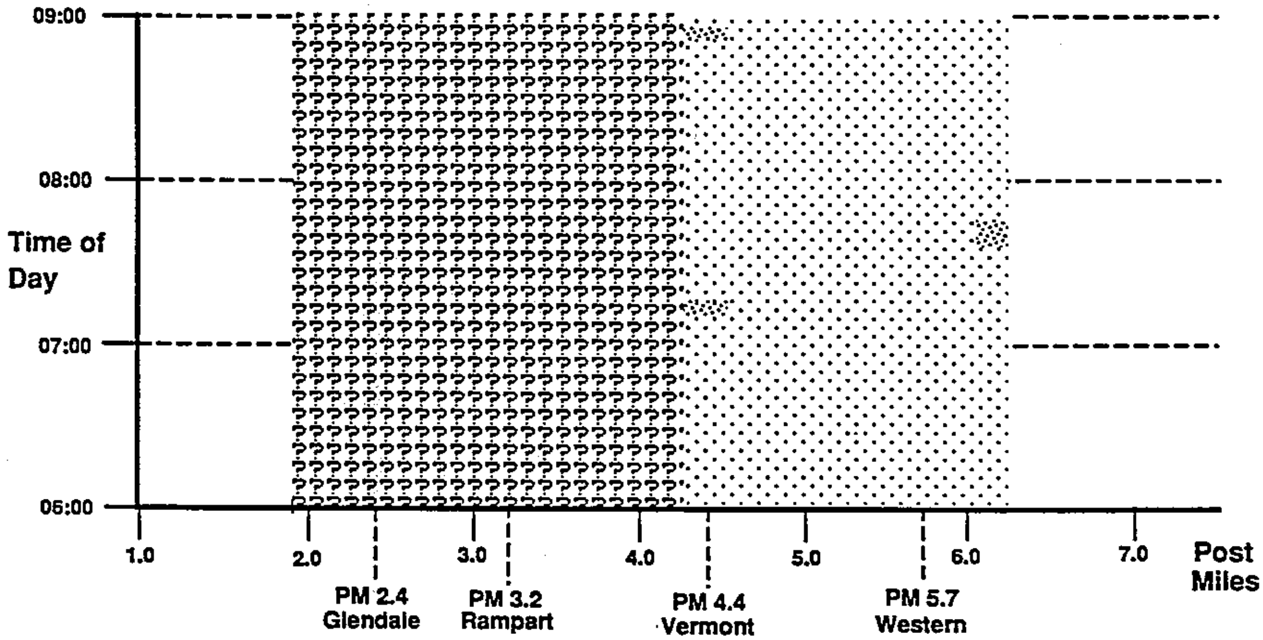


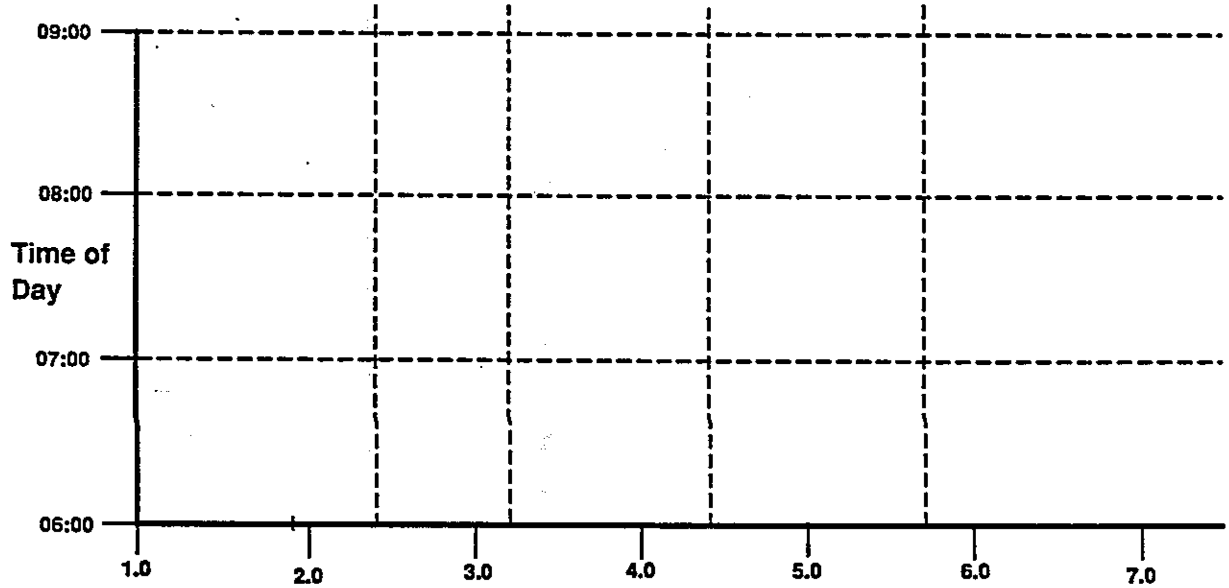
Volume Density Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/24/85 - Upper Plot ##/##/## - Lower Plot





LEGEND (no. of cars / lane * hr)

- < 1500
- 1500 - 1650
- 1650 - 1800
- 1800 - 1900
- 1900 - 2000
- 2000 - 2100
- > 2100
- undefined

Direction of travel ---->>

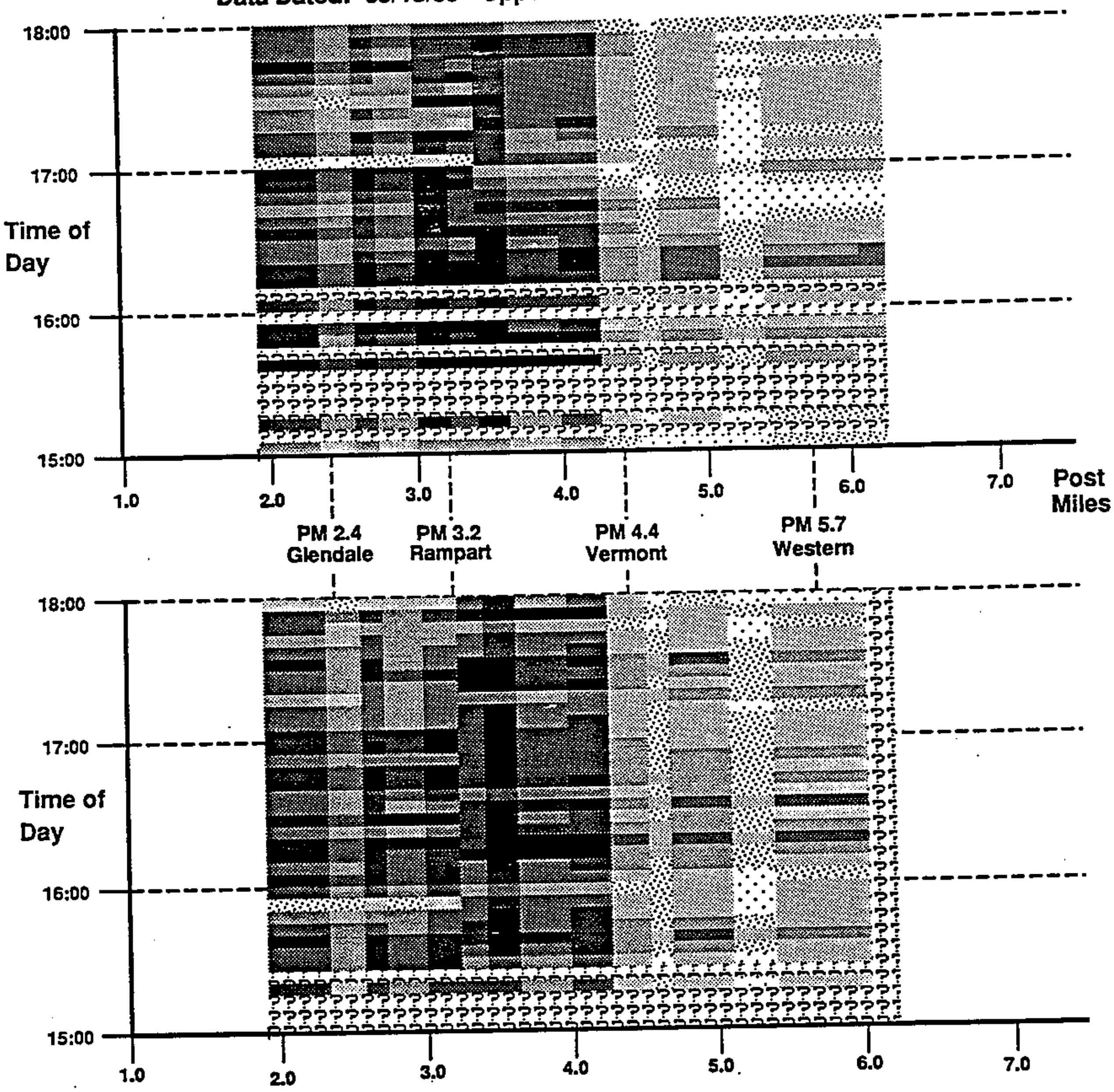
Scale: H: 1" = 1 mile, V: 1" = hour

Volume Density Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/13/85 - Upper Plot 05/14/85 - Lower Plot



Direction of travel ---->>

LEGEND (no. of cars / lane * hr)

	< 1500		1900 - 2000
	1500 - 1650		2000 - 2100
	1650 -1800		> 2100
	1800 - 1900	??????	undefined

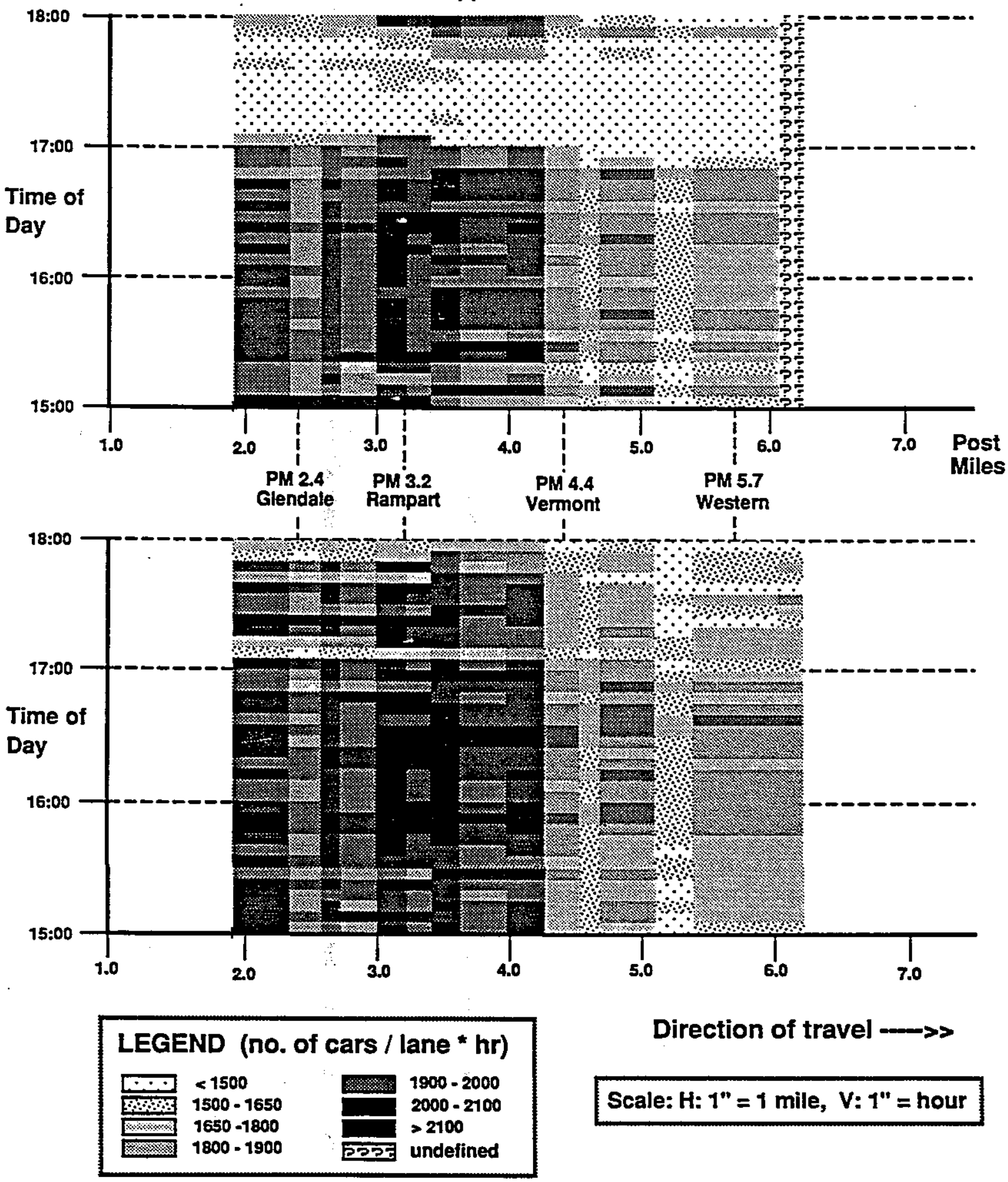
Scale: H: 1" = 1 mile, V: 1" = hour

Volume Density Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/15/85 - Upper Plot 05/16/85 - Lower Plot

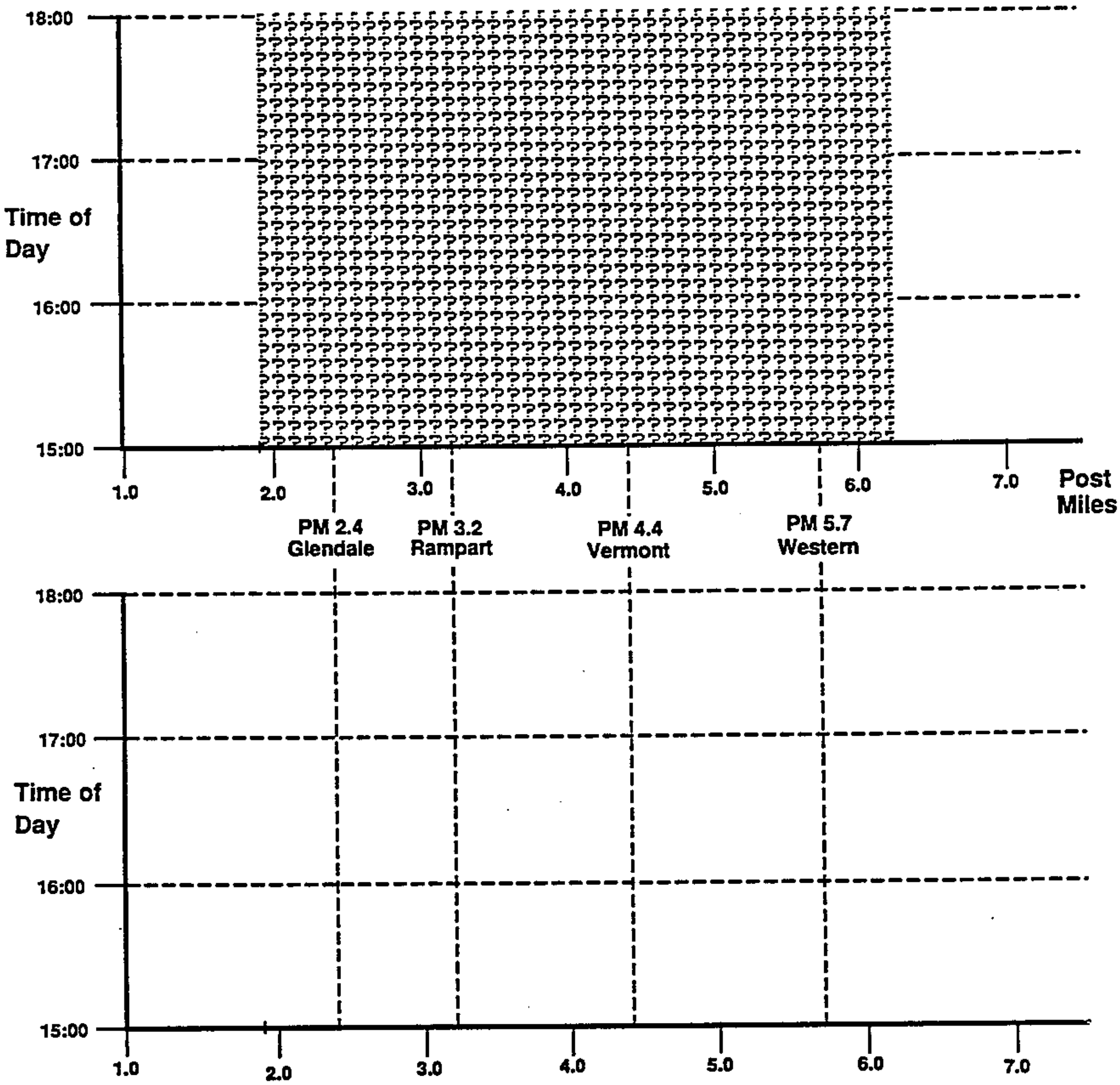


Volume Density Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/17/85 - Upper Plot ##/##/## - Lower Plot



LEGEND (no. of cars / lane * hr)

< 1500	1900 - 2000
1500 - 1650	2000 - 2100
1650 -1800	> 2100
1800 - 1900	undefined

Direction of travel ---->>

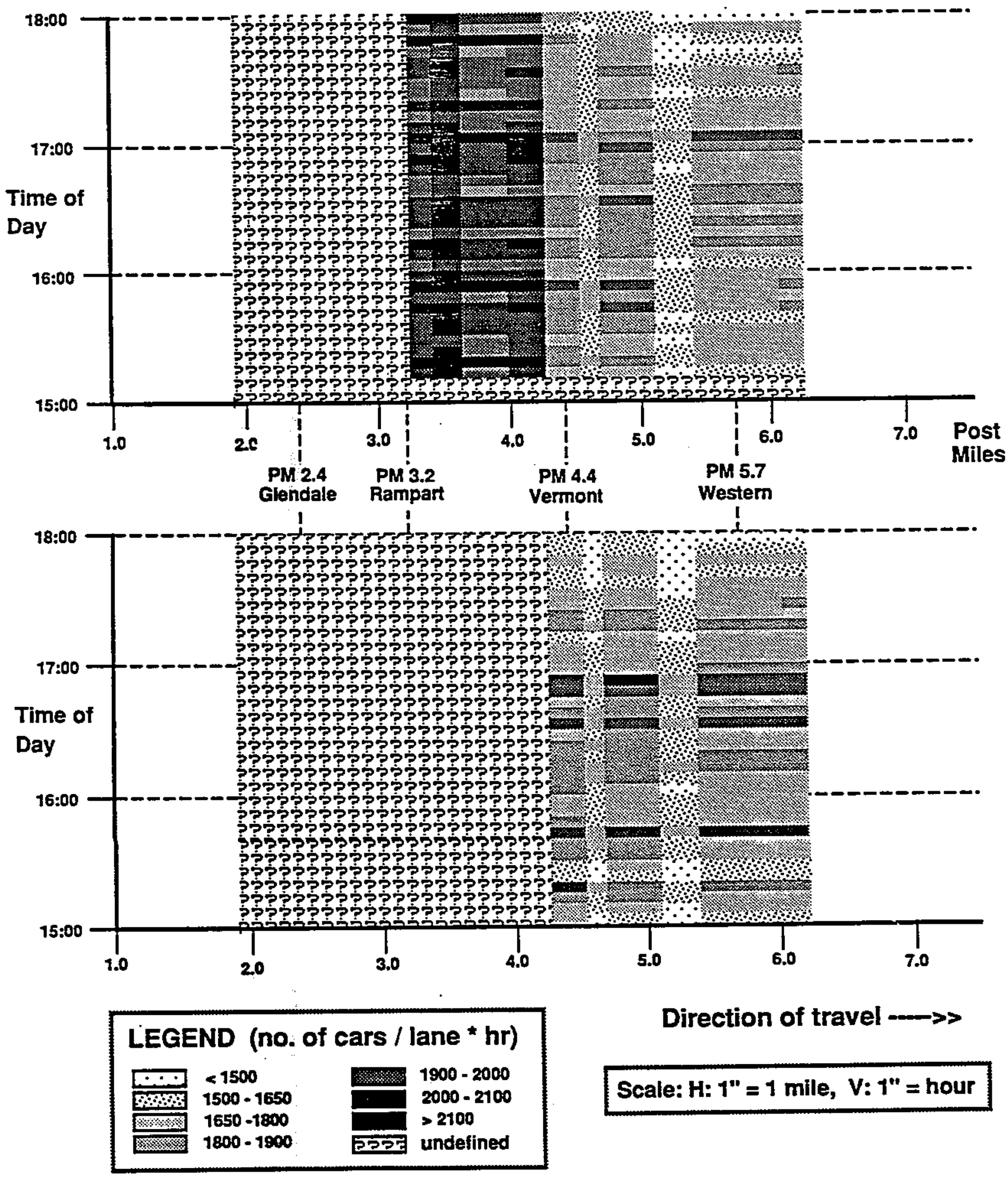
Scale: H: 1" = 1 mile, V: 1" = hour

Volume Density Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/20/85 - Upper Plot 05/21/85 - Lower Plot

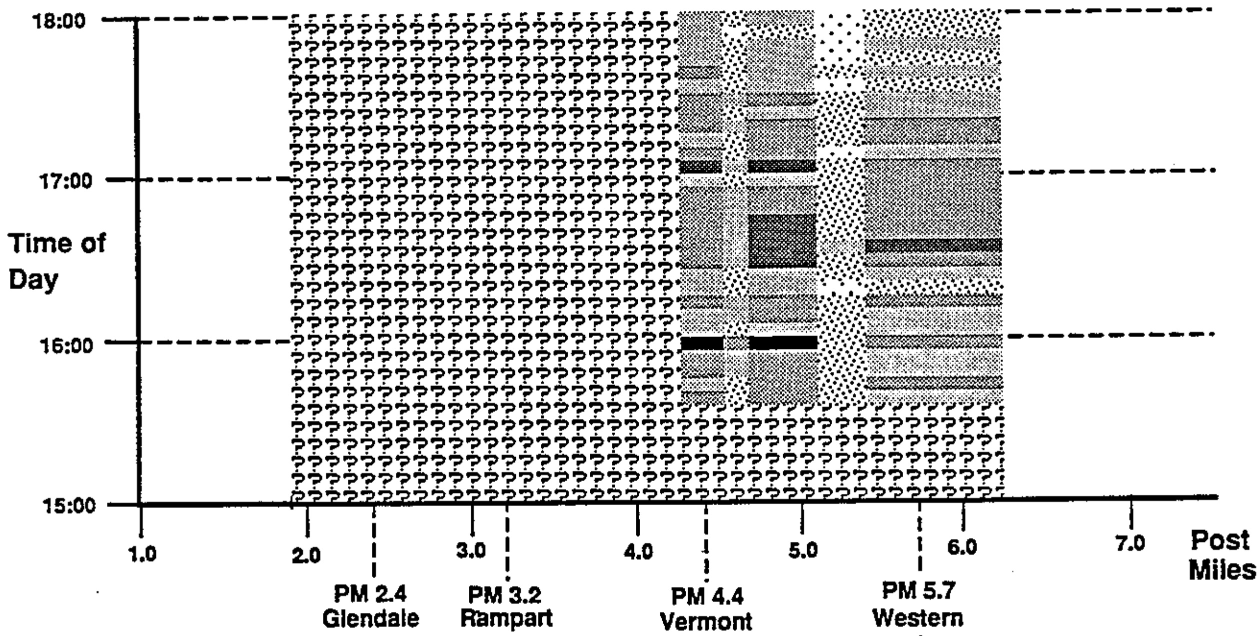


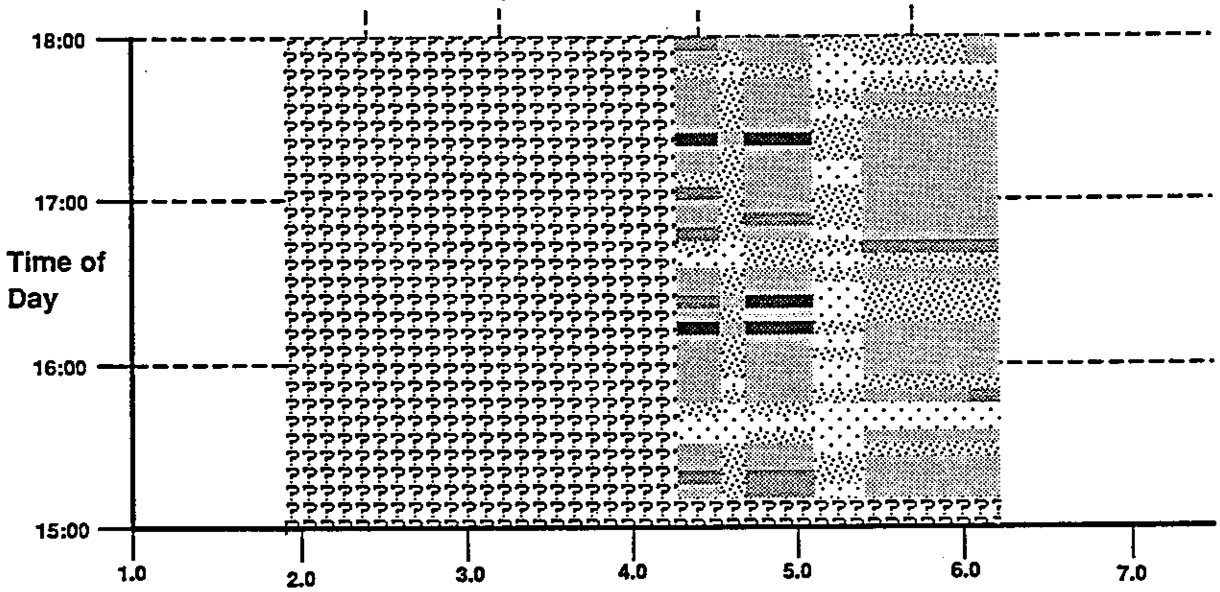
Volume Density Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/22/85 - Upper Plot 05/23/85 - Lower Plot





LEGEND (no. of cars / lane * hr)

< 1500	1900 - 2000
1500 - 1650	2000 - 2100
1650 -1800	> 2100
1800 - 1900	undefined

Direction of travel ---->>

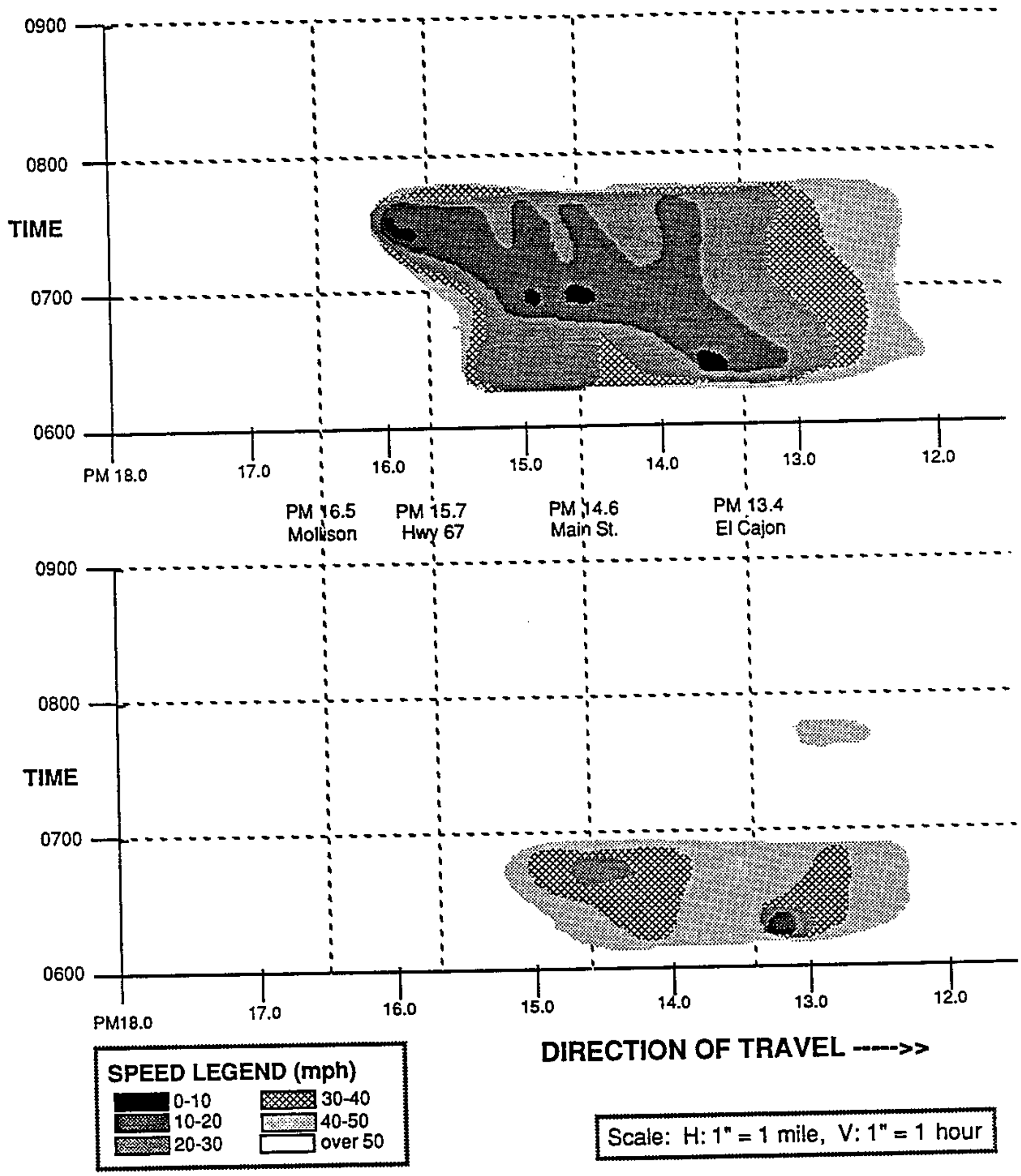
Scale: H: 1" = 1 mile, V: 1" = hour

APPENDIX D

Speed Contour Plots

Westbound Hwy 8, San Diego
Morning

Data Dated: 04/09/85 - Upper Plot 04/10/85 - Lower Plot

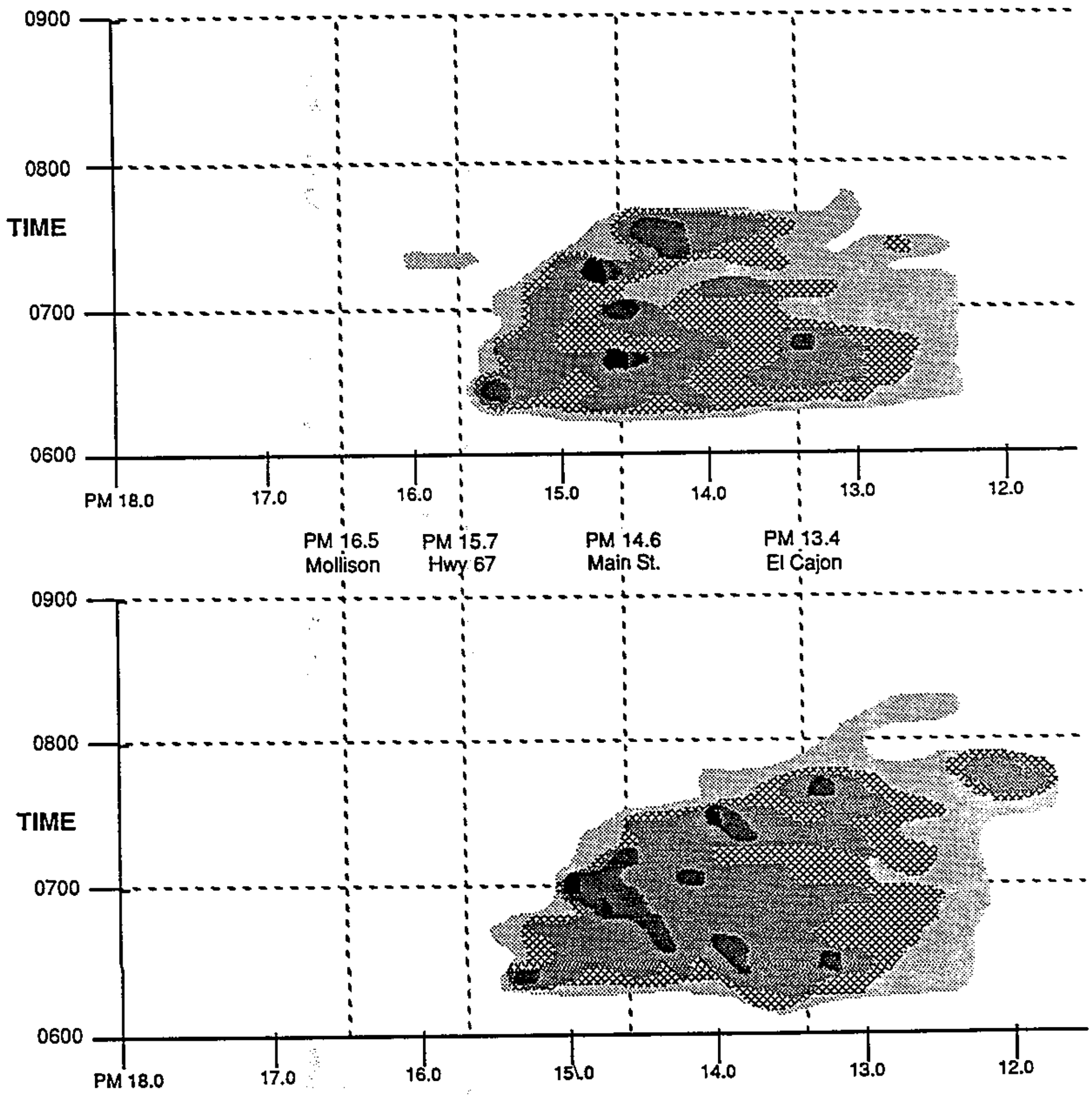


Speed Contour Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/11/85 - Upper Plot 04/12/85 - Lower Plot



SPEED LEGEND (mph)

0-10
10-20
20-30
30-40
40-50
over 50

DIRECTION OF TRAVEL ---->>

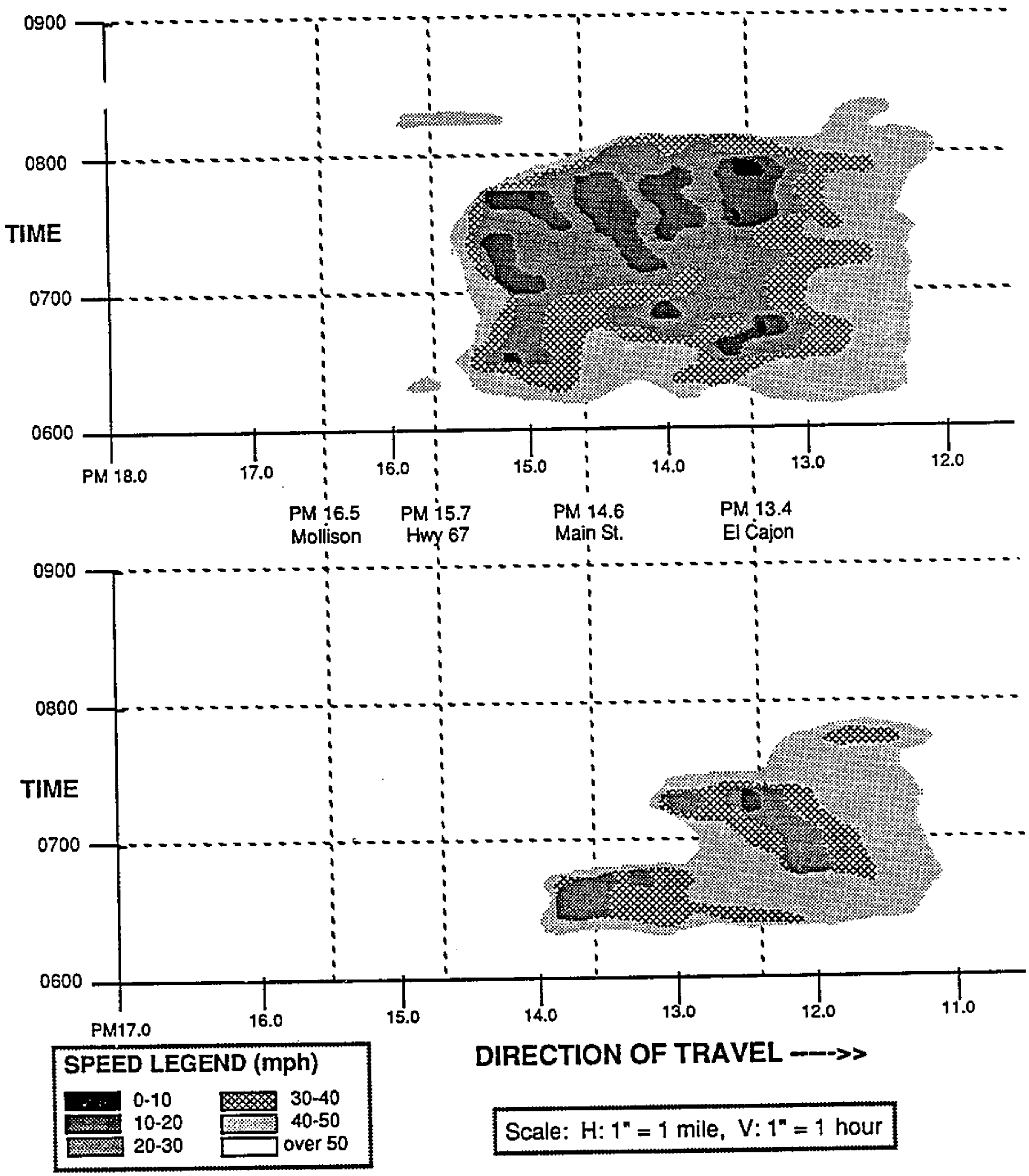
Scale: H: 1" = 1 mile, V: 1" = 1 hour

Speed Contour Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/15/85 - Upper Plot 04/16/85 - Lower Plot

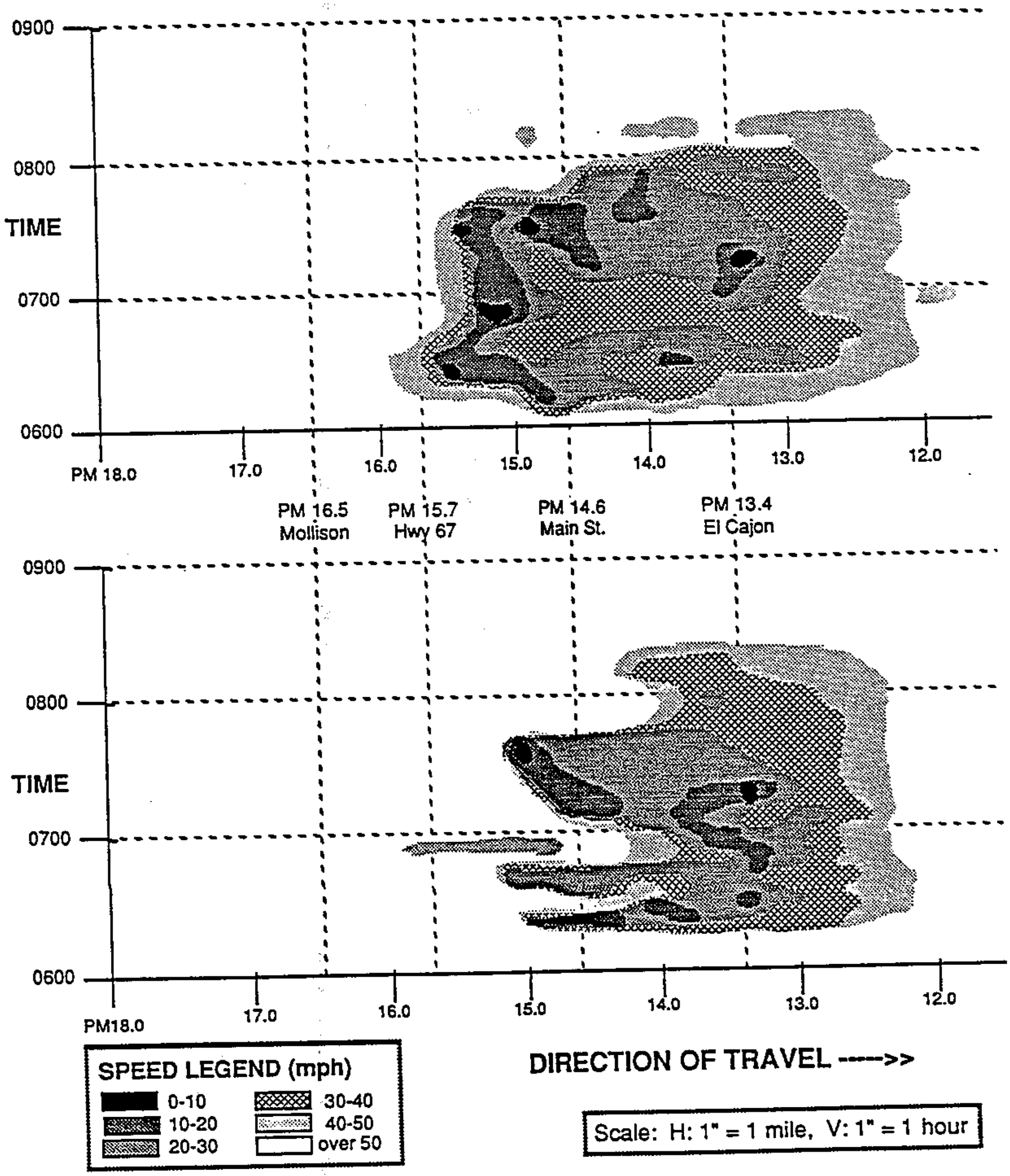


Speed Contour Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/17/85 - Upper Plot 04/18/85 - Lower Plot

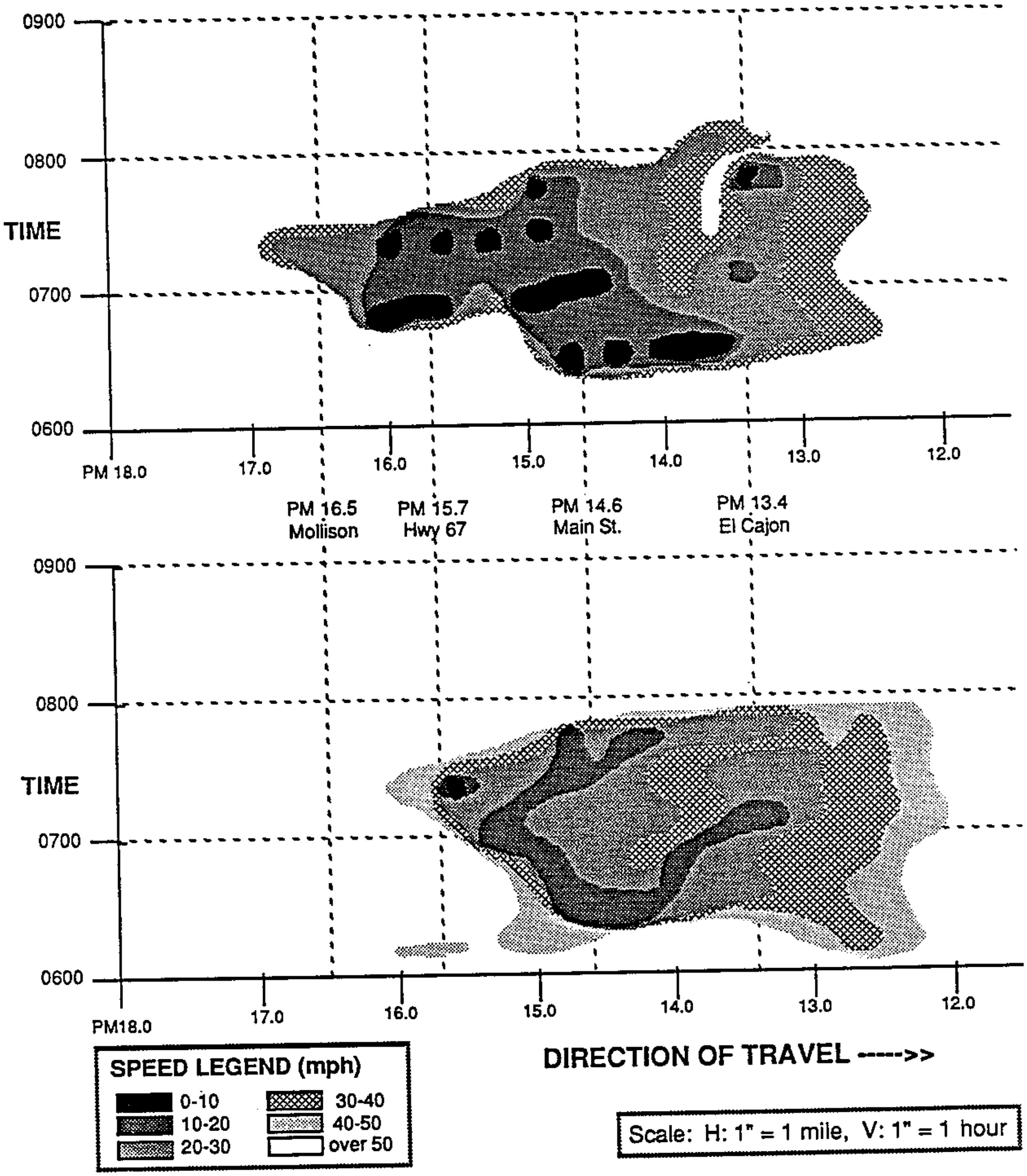


Speed Contour Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/19/85 - Upper Plot 04/22/85 - Lower Plot

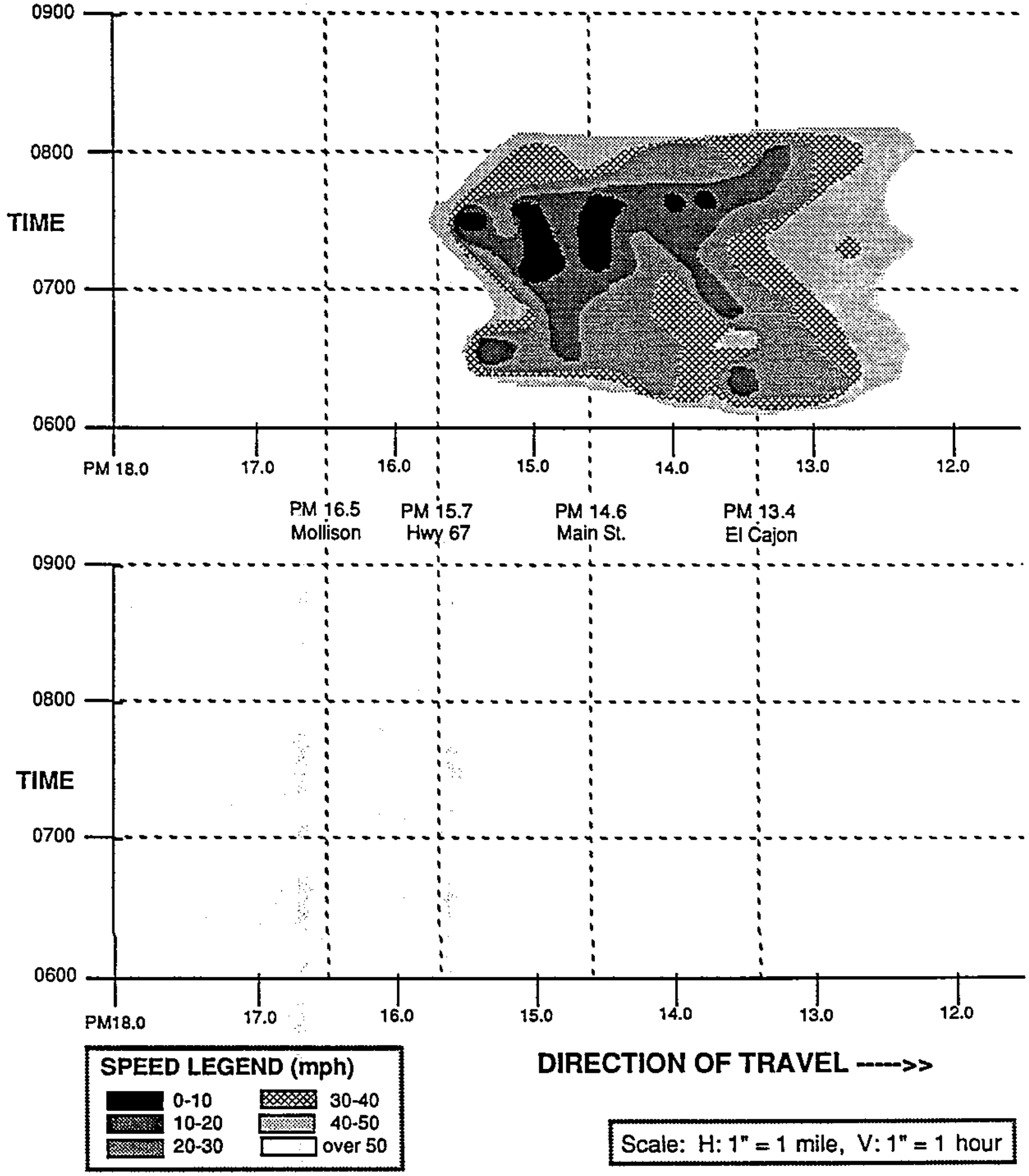


Speed Contour Plots

Westbound Hwy 8, San Diego

Morning

Data Dated: 04/23/85 - Upper Plot ##/##/## - Lower Plot

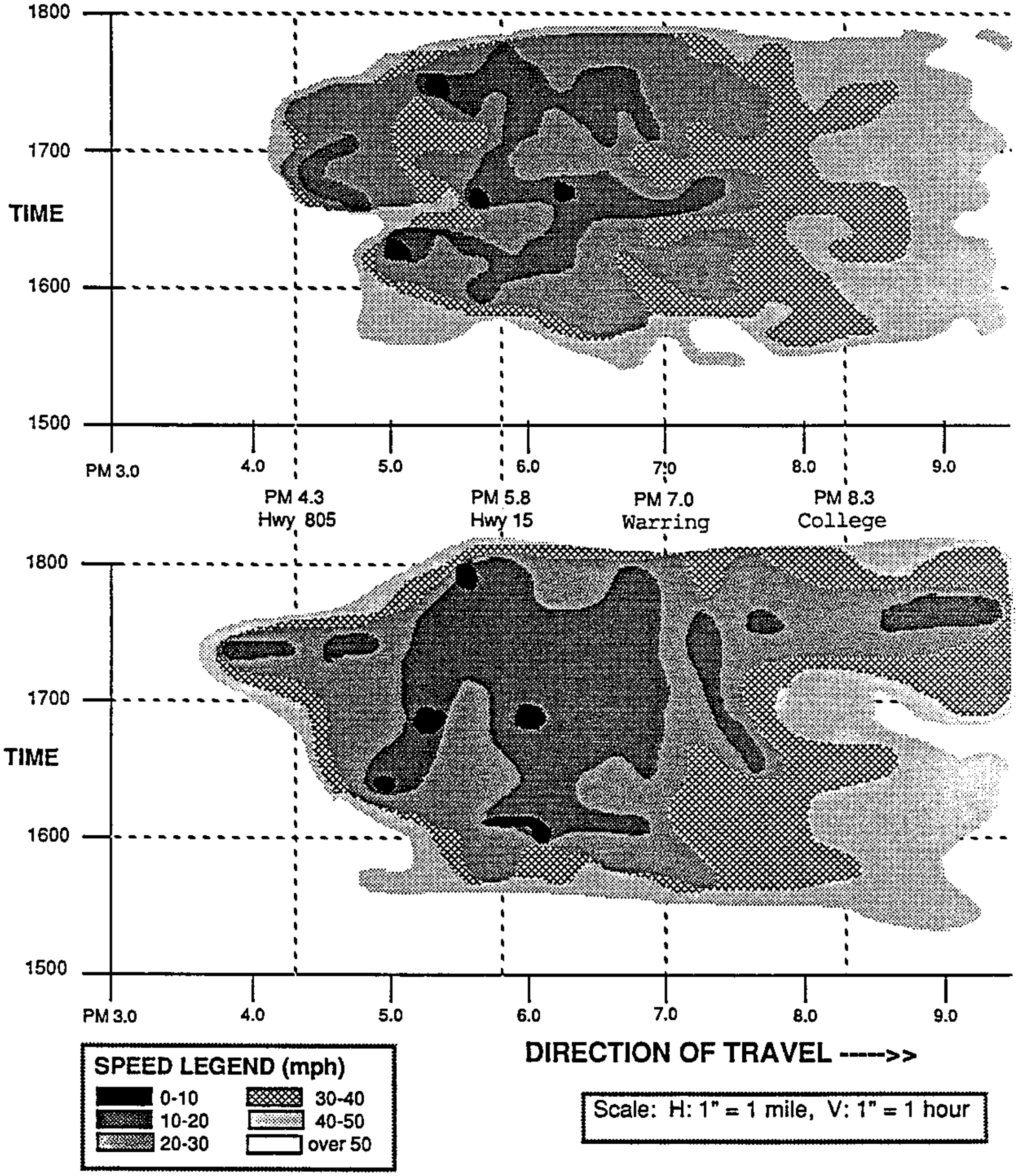


Speed Contour Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/11/85 - Upper Plot 04/12/85 - Lower Plot

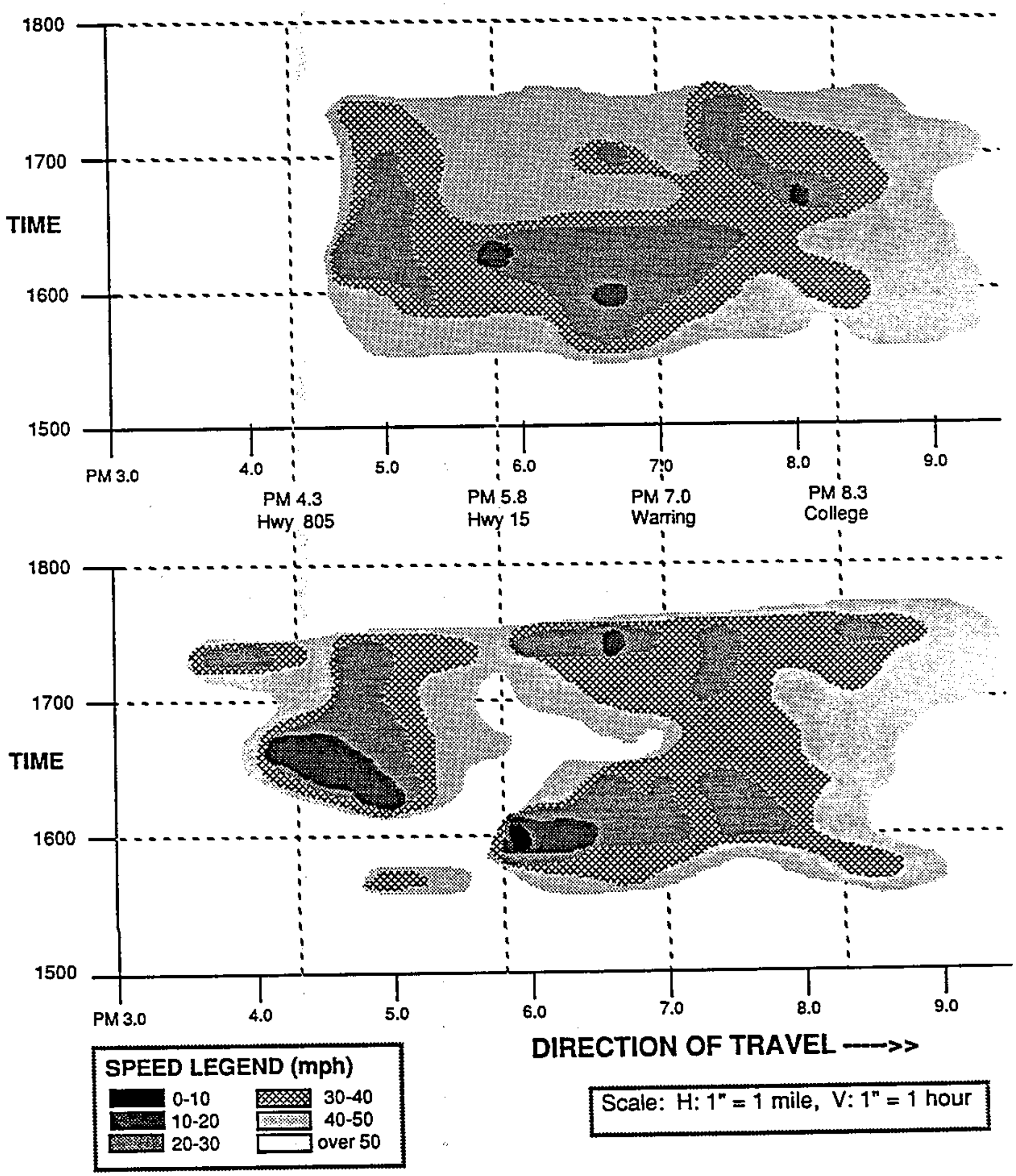


Speed Contour Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/15/85 - Upper Plot 04/17/85 - Lower Plot

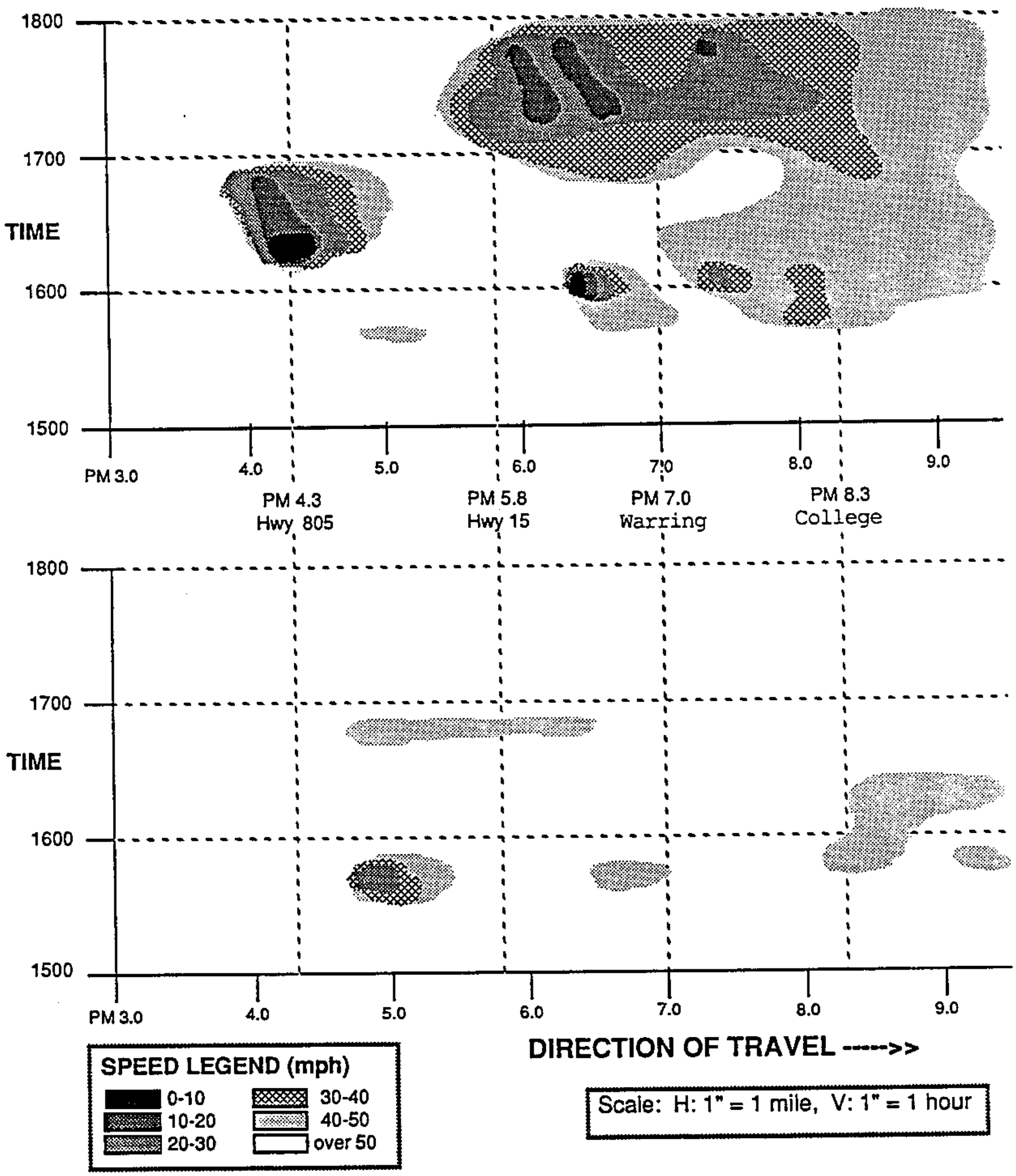


Speed Contour Plots

Eastbound Hwy 8, San Diego

Evening

Data Dated: 04/18/85 - Upper Plot 04/22/85 - Lower Plot

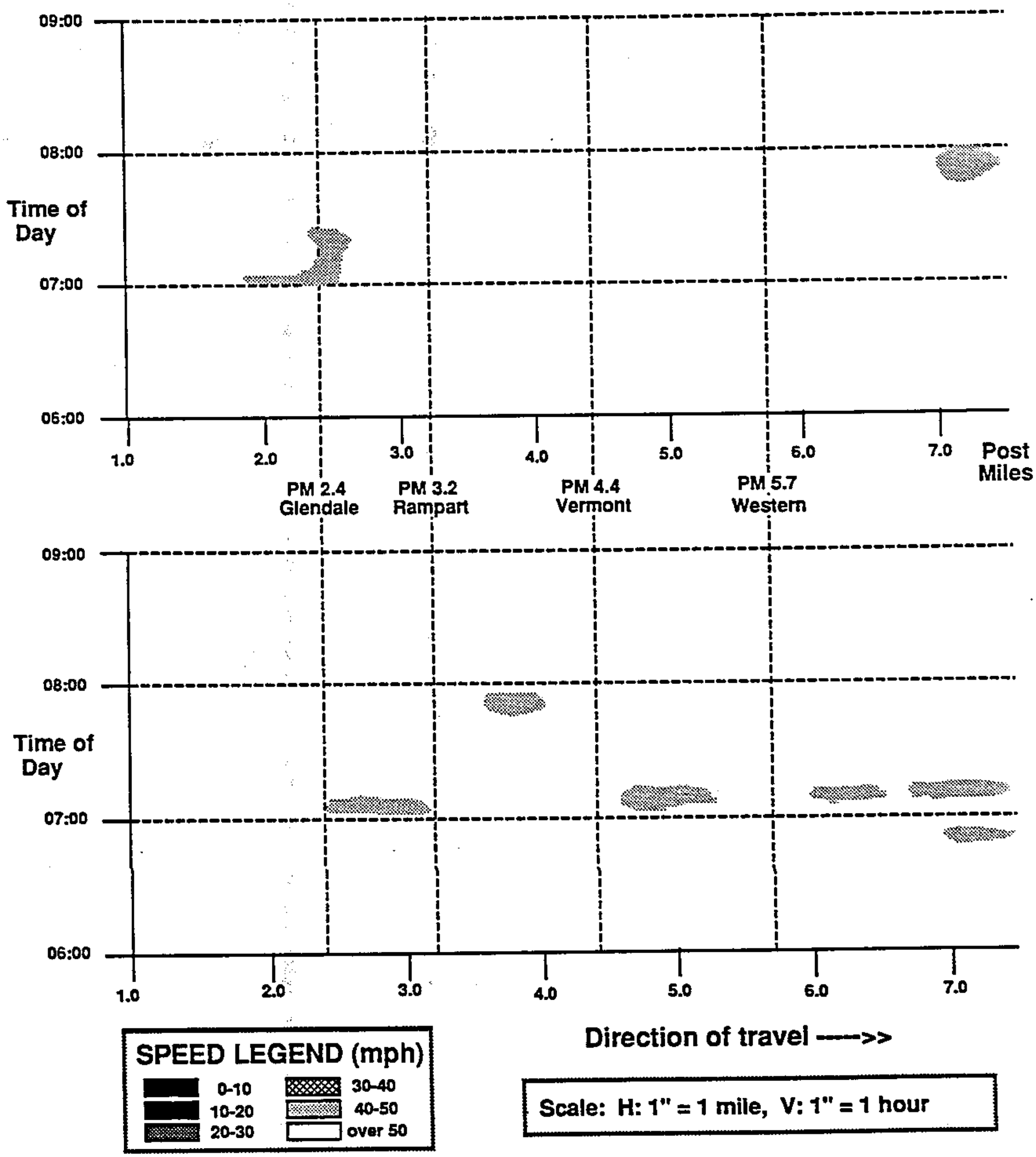


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/13/85 - Upper Plot 05/14/85 - Lower Plot

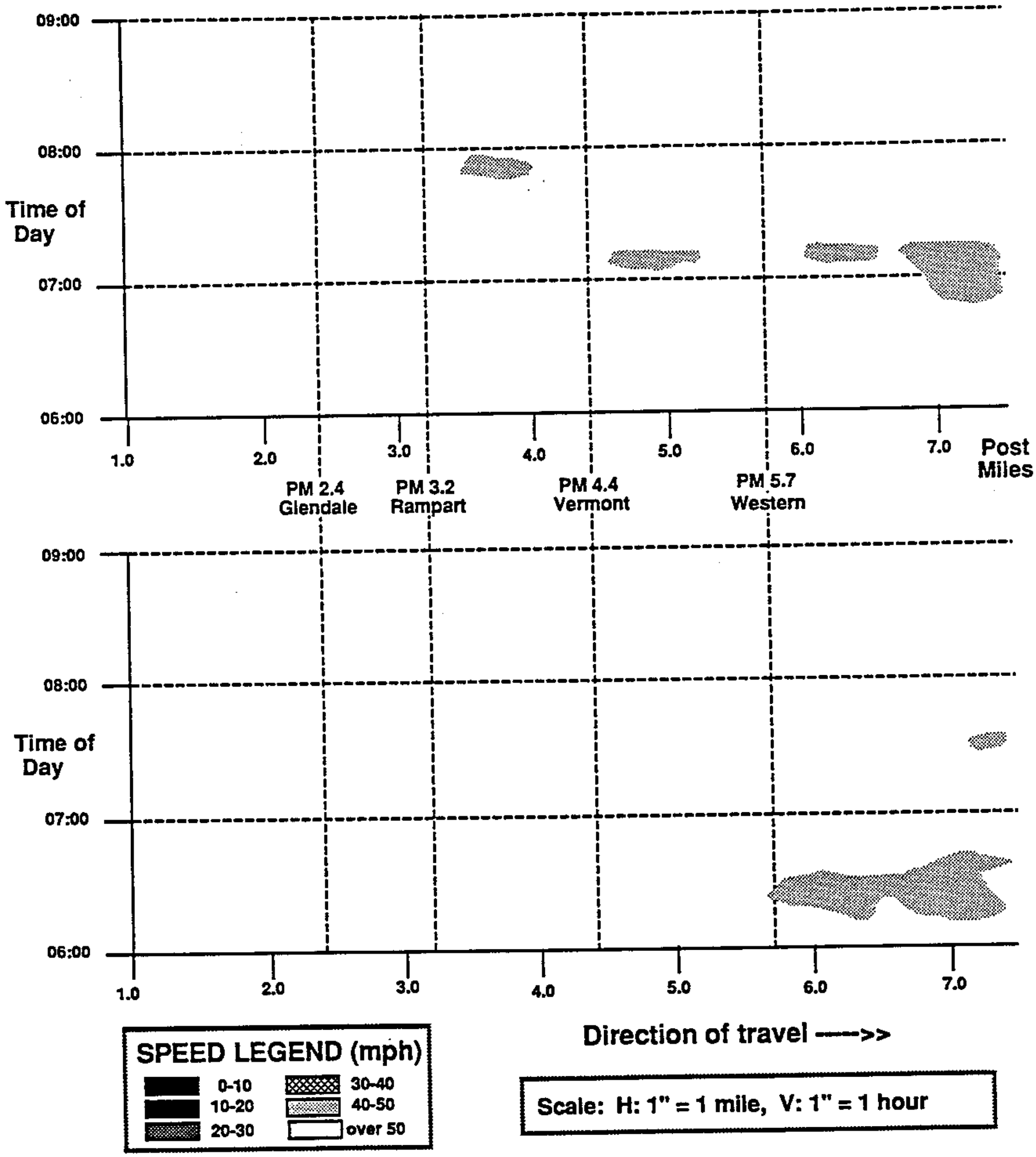


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/15/85 - Upper Plot 05/16/85 - Lower Plot

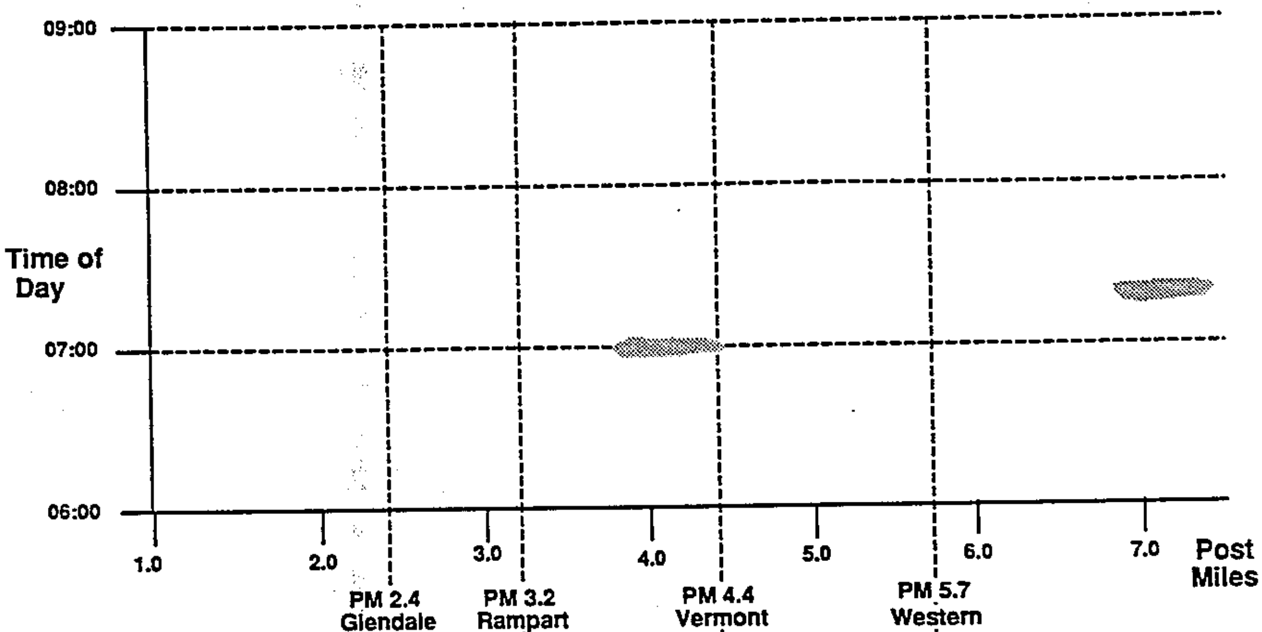


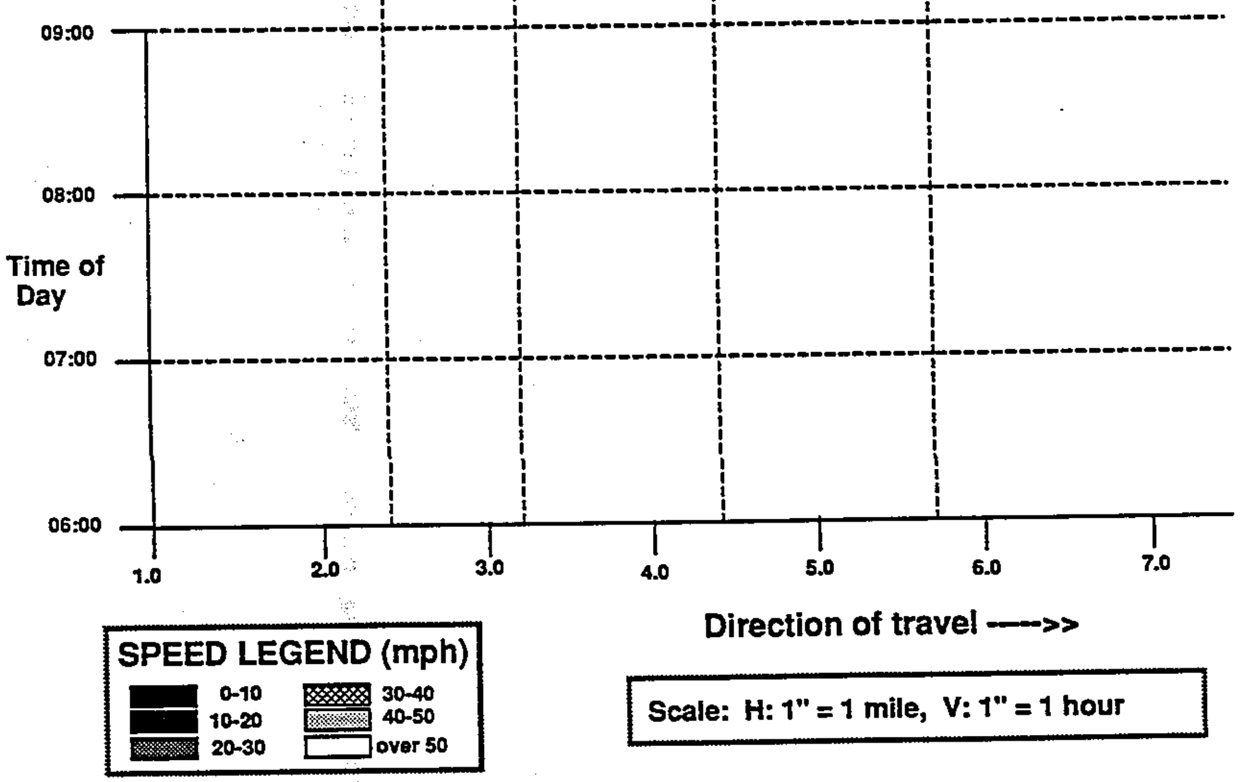
Speed Contour Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/17/85 - Upper Plot ##/##/## - Lower Plot



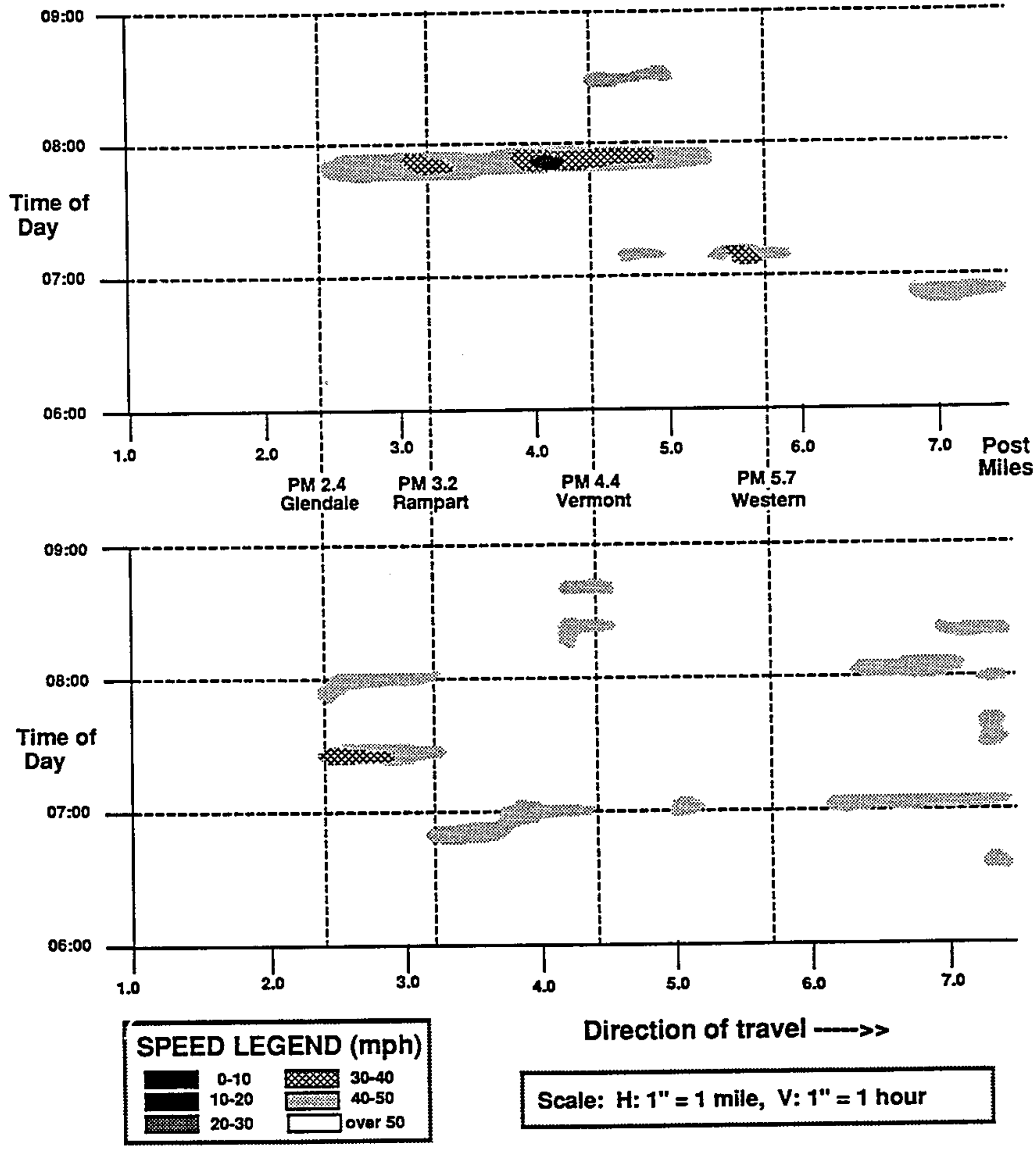


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/20/85 - Upper Plot   05/21/85 - Lower Plot

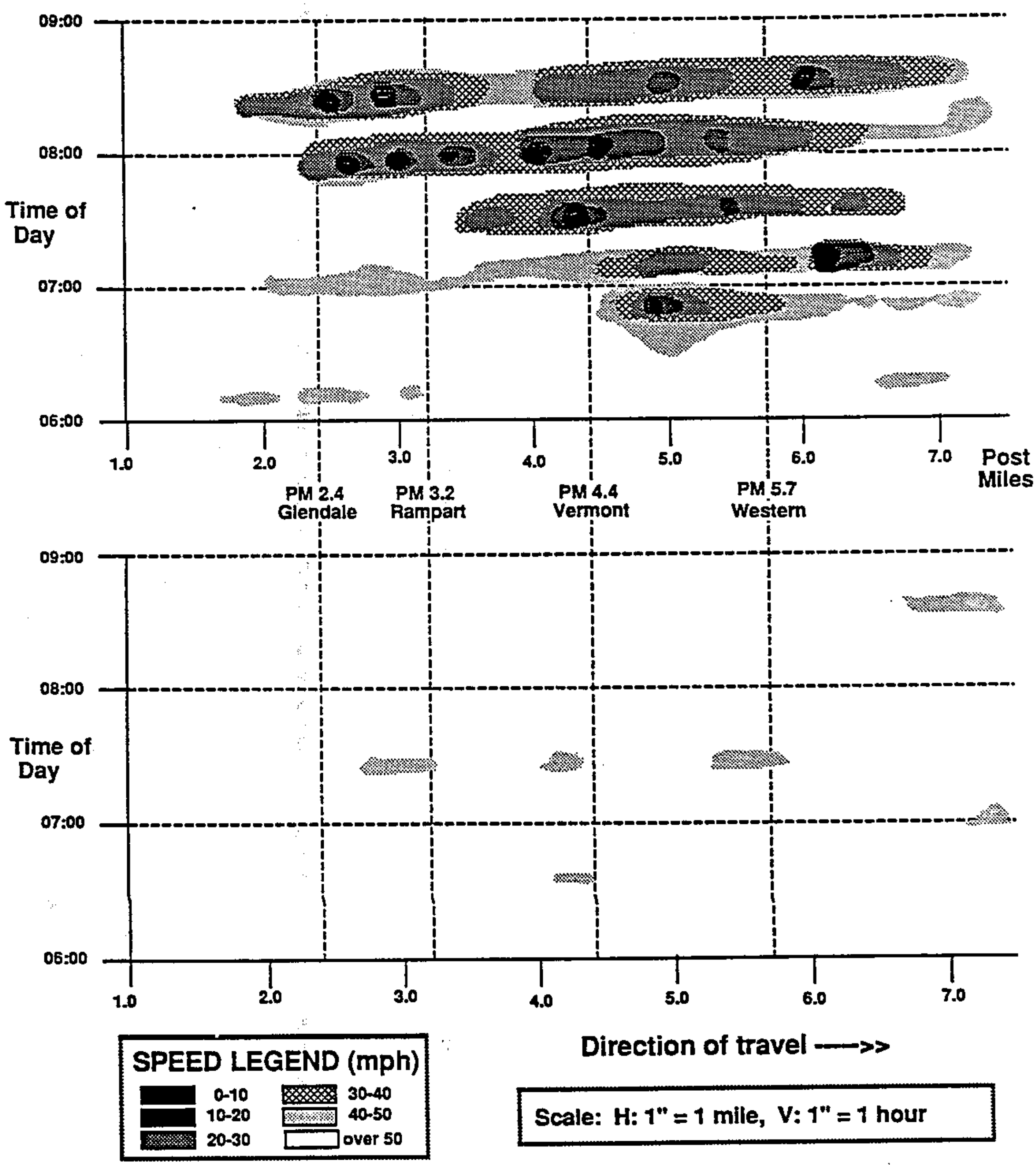


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/22/85 - Upper Plot 05/23/85 - Lower Plot

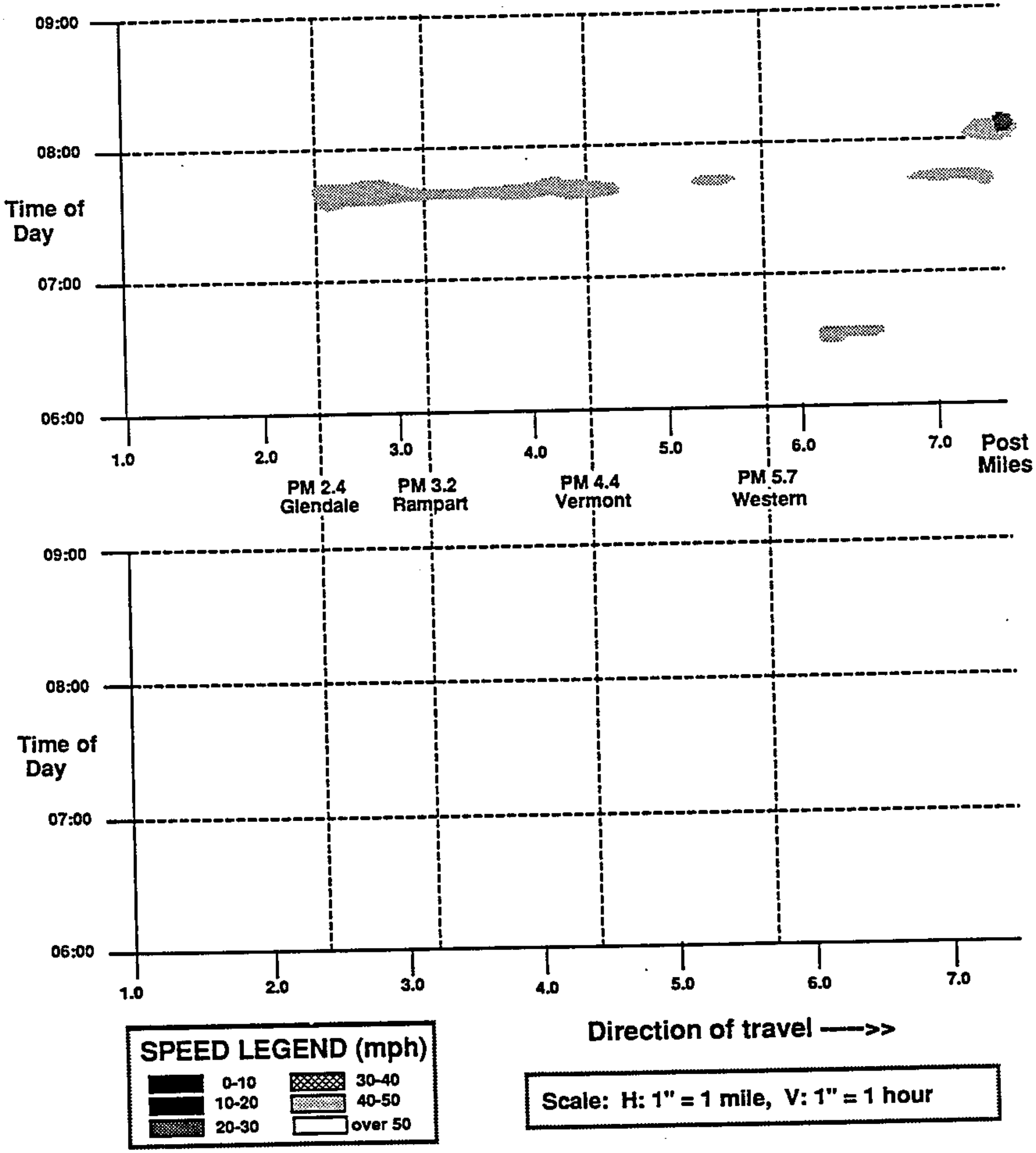


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Morning

Data Dated: 05/24/85 - Upper Plot ##/##/## - Lower Plot

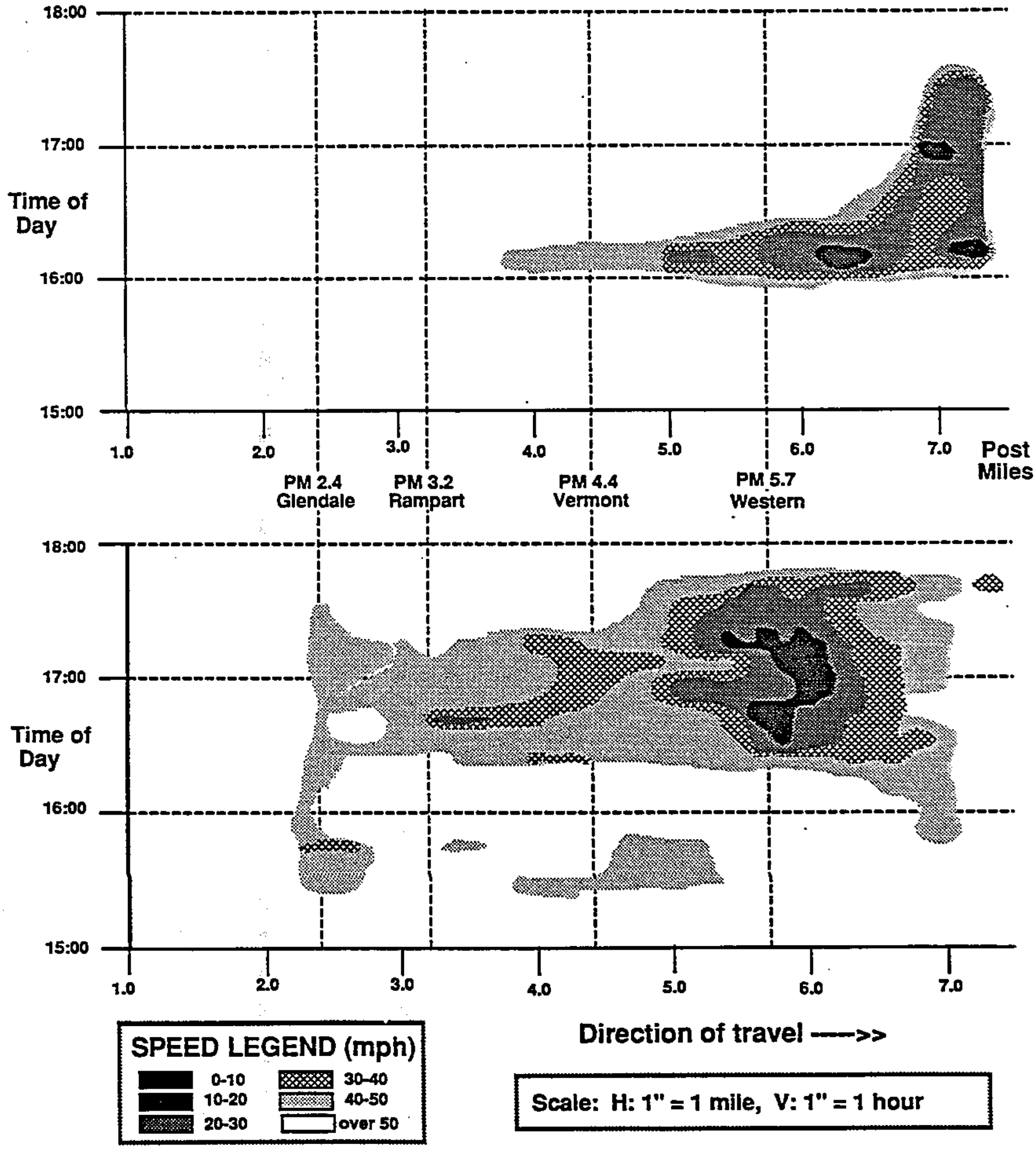


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/13/85 - Upper Plot 05/14/85 - Lower Plot

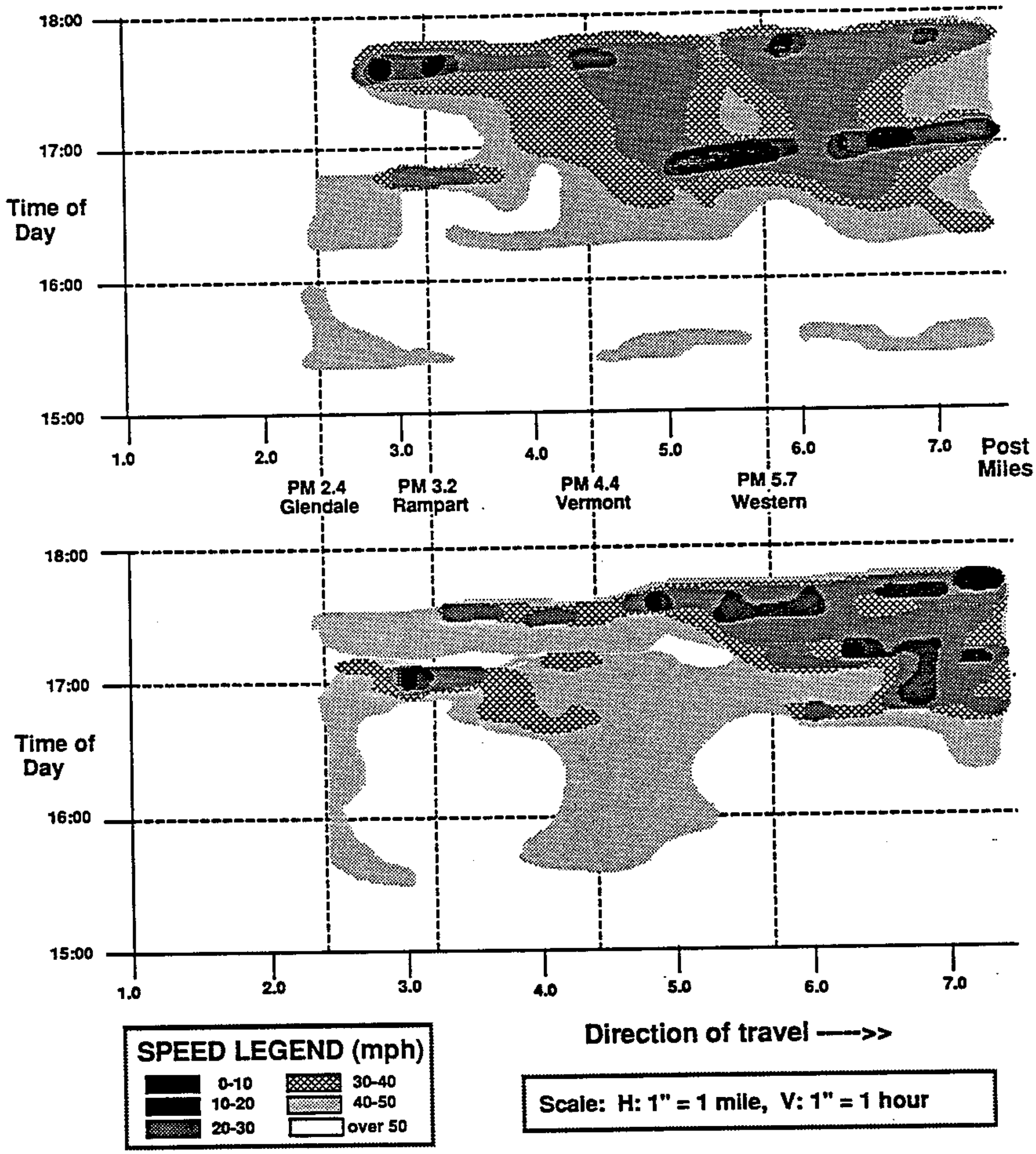


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/15/85 - Upper Plot 05/16/85 - Lower Plot

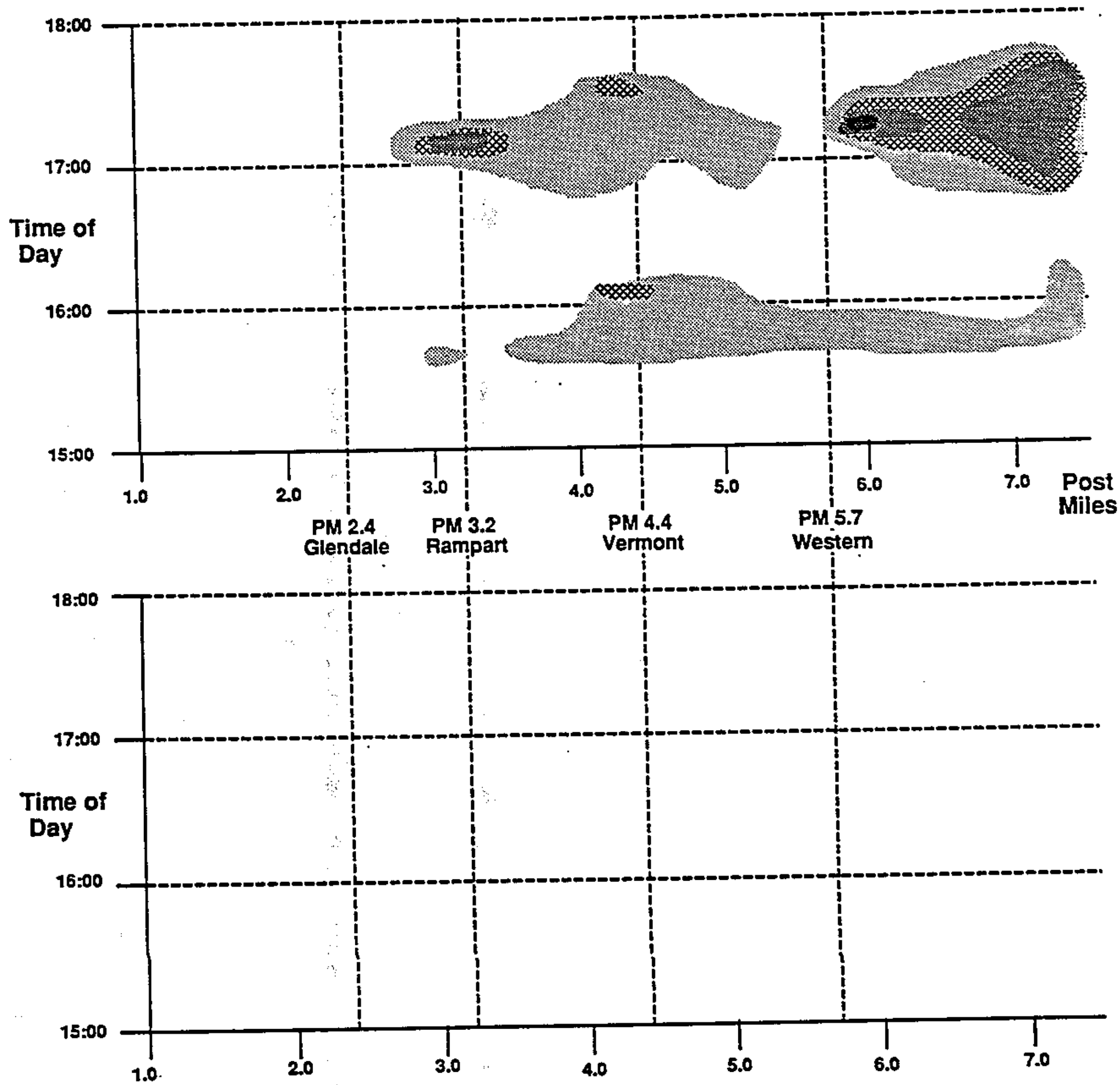


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/17/85 - Upper Plot ##/##/## - Lower Plot



Direction of travel ——>>

SPEED LEGEND (mph)

0-10	30-40
10-20	40-50
20-30	over 50

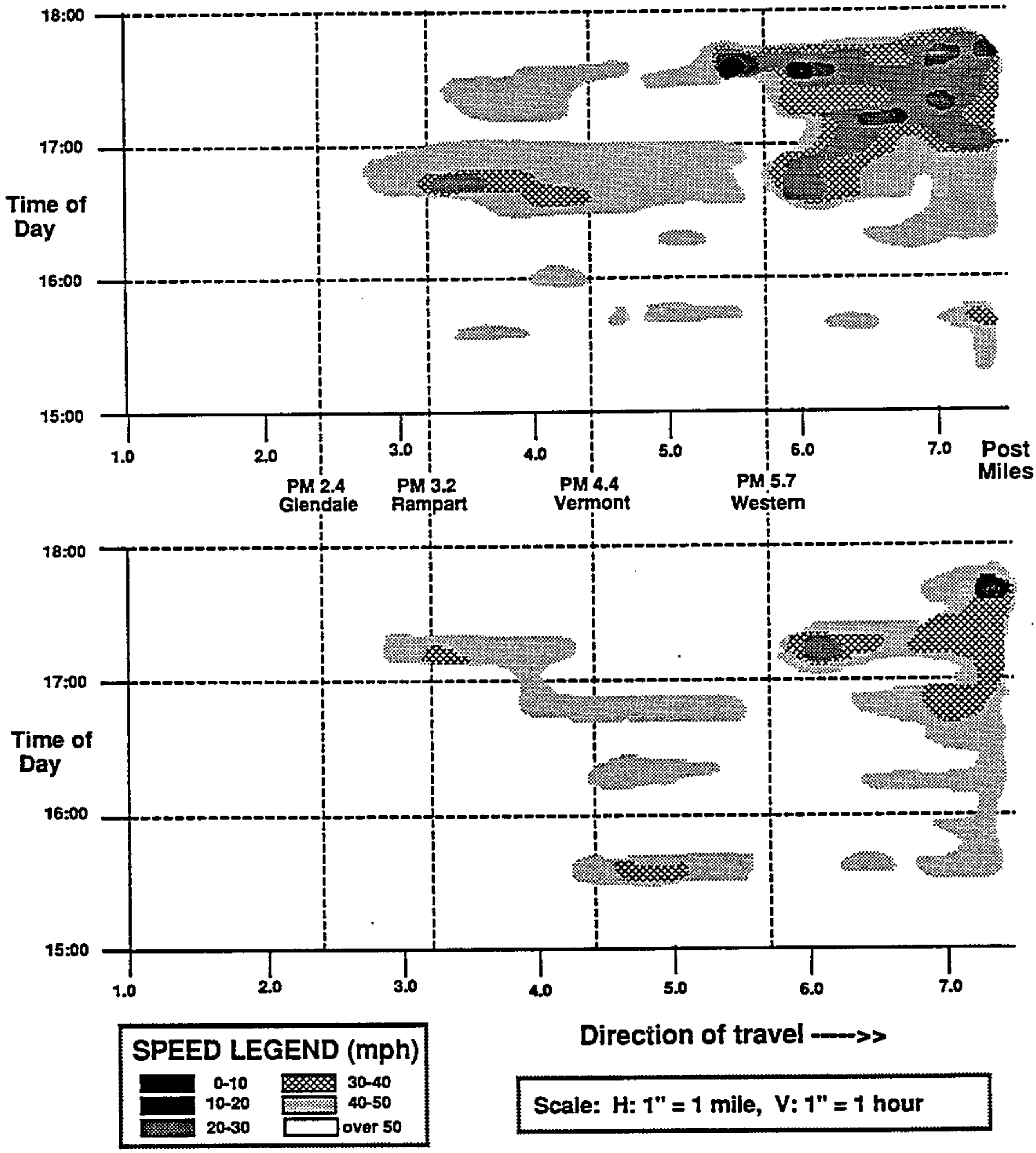
Scale: H: 1" = 1 mile, V: 1" = 1 hour

Speed Contour Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/20/85 - Upper Plot 05/21/85 - Lower Plot

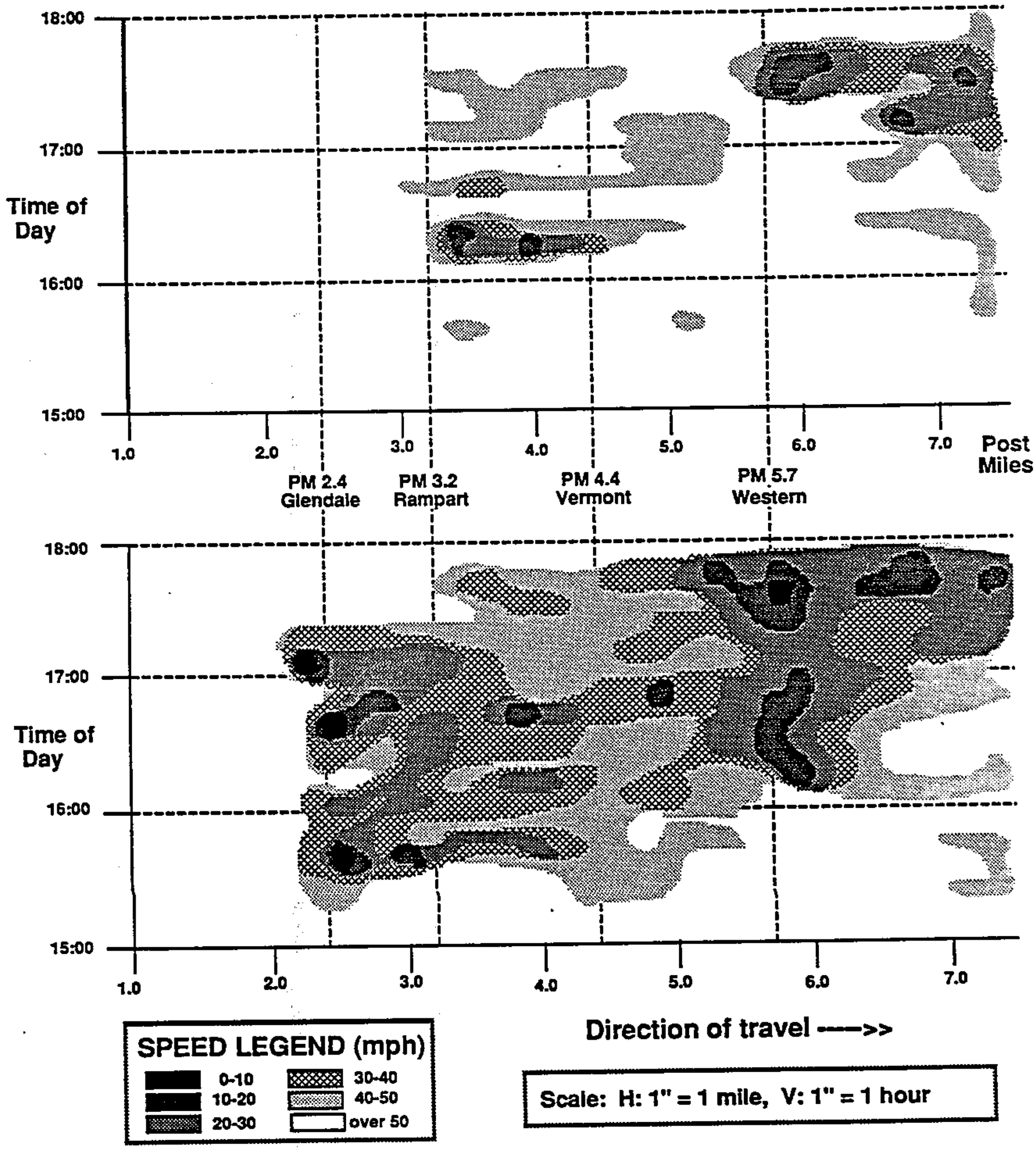


Speed Contour Plots

Northbound Hwy 101, Los Angeles

Evening

Data Dated: 05/22/85 - Upper Plot 05/23/85 - Lower Plot

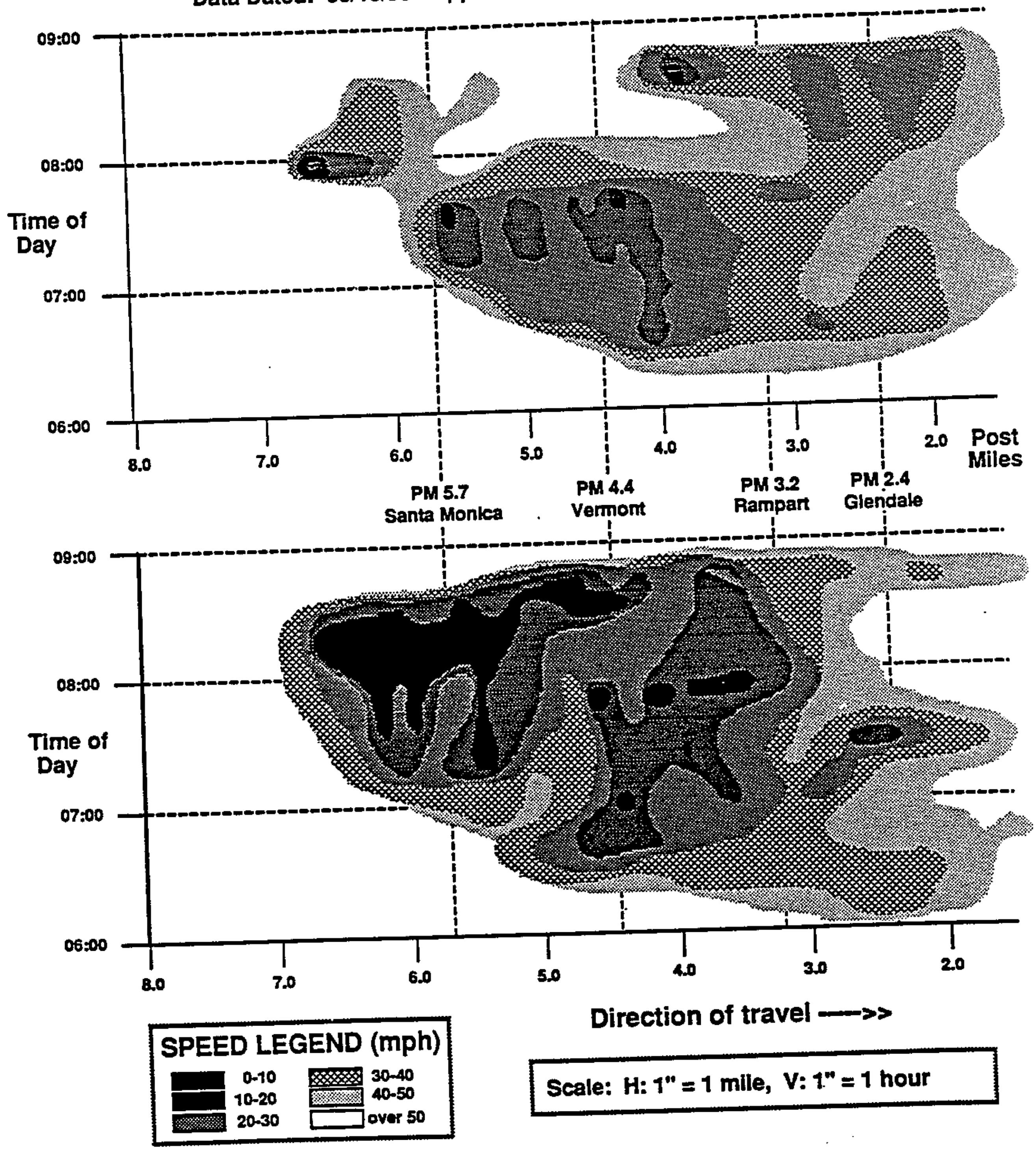


Speed Contour Plots

Southbound Hwy 101, Los Angeles

Morning

Data Dated: 05/13/85 - Upper Plot 05/14/85 - Lower Plot

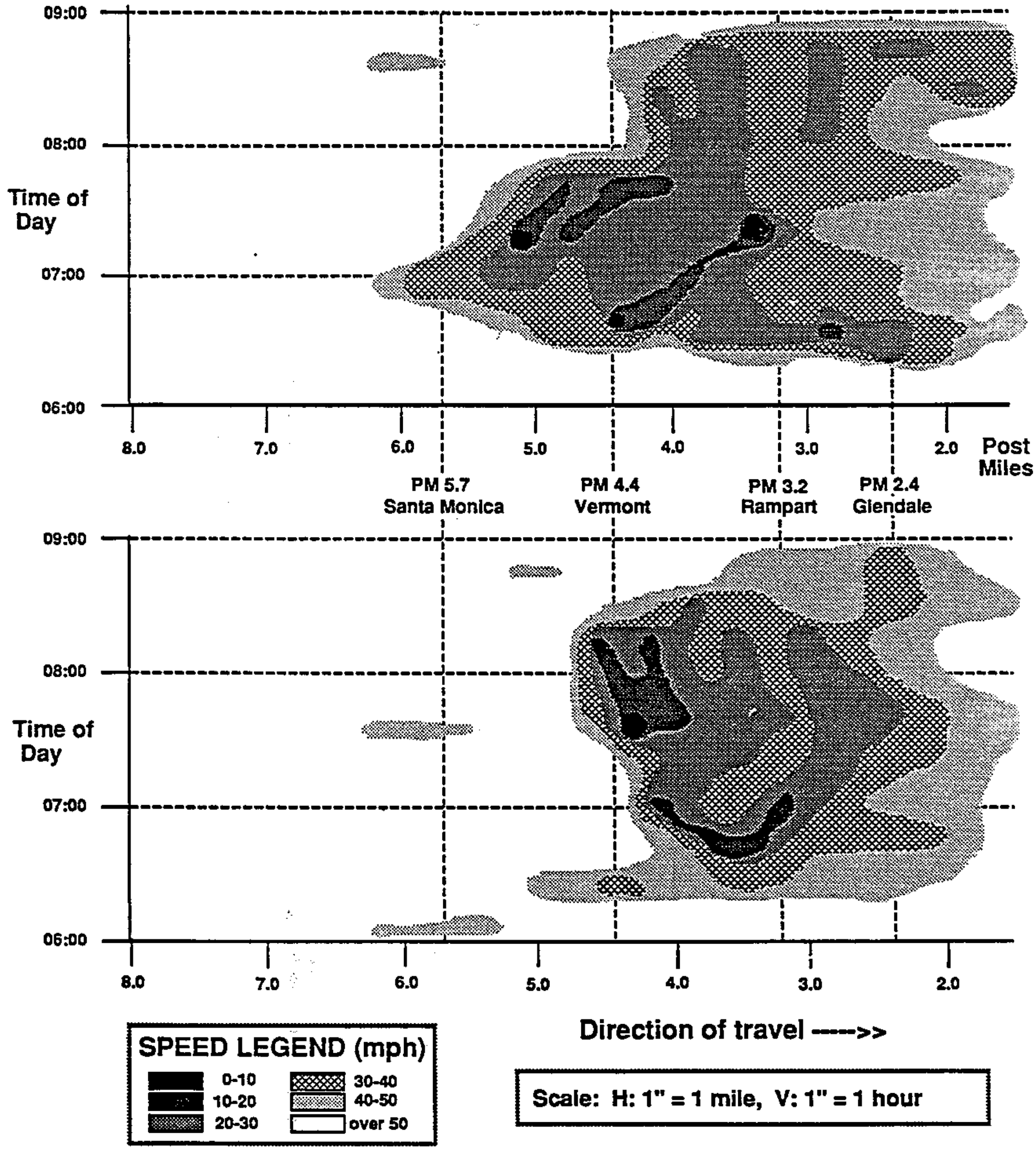


Speed Contour Plots

Southbound Hwy 101, Los Angeles

Morning

Data Dated: 05/15/85 - Upper Plot 05/16/85 - Lower Plot

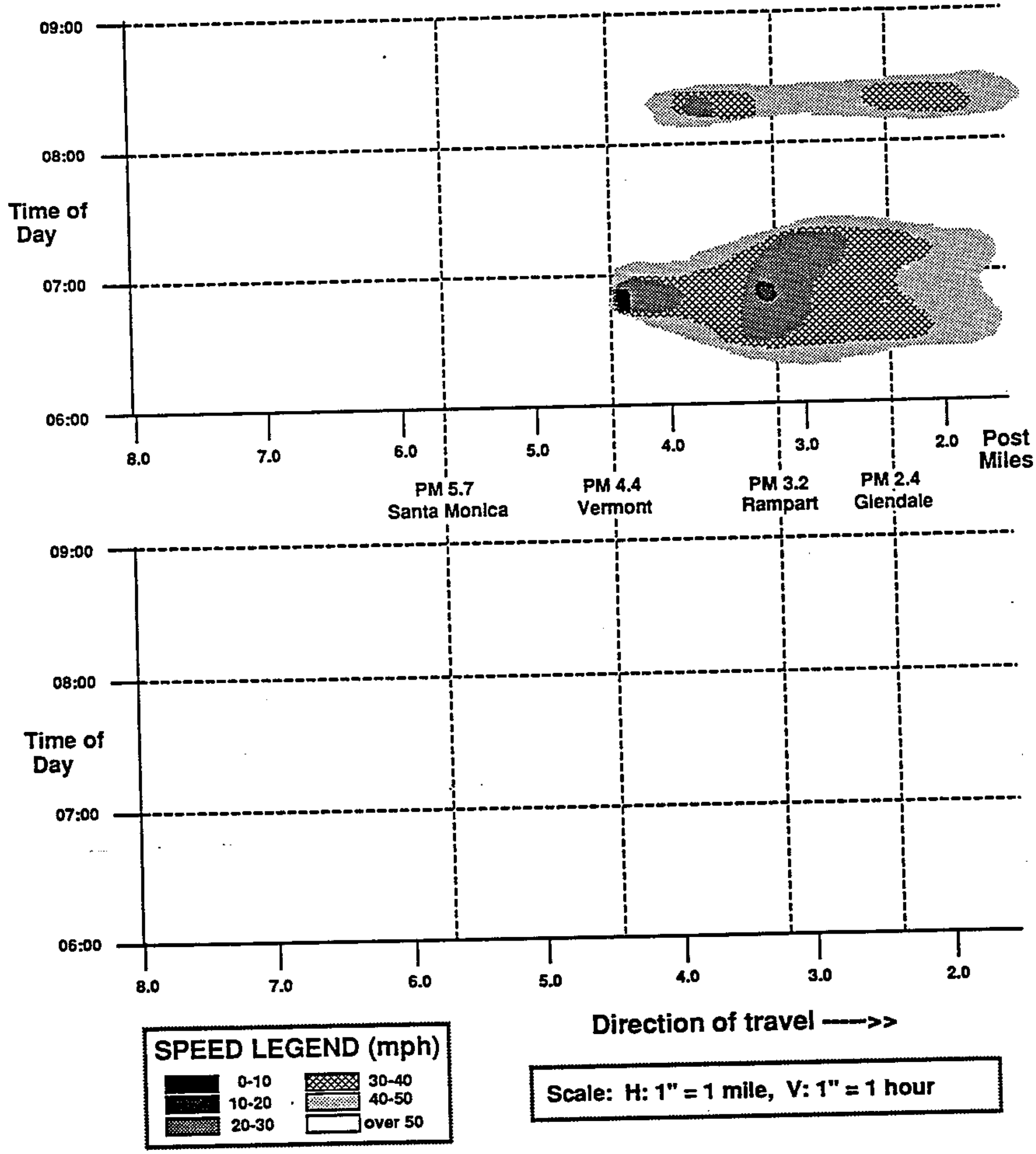


Speed Contour Plots

Southbound Hwy 101, Los Angeles

Morning

Data Dated: 05/17/85 - Upper Plot ##/##/## - Lower Plot

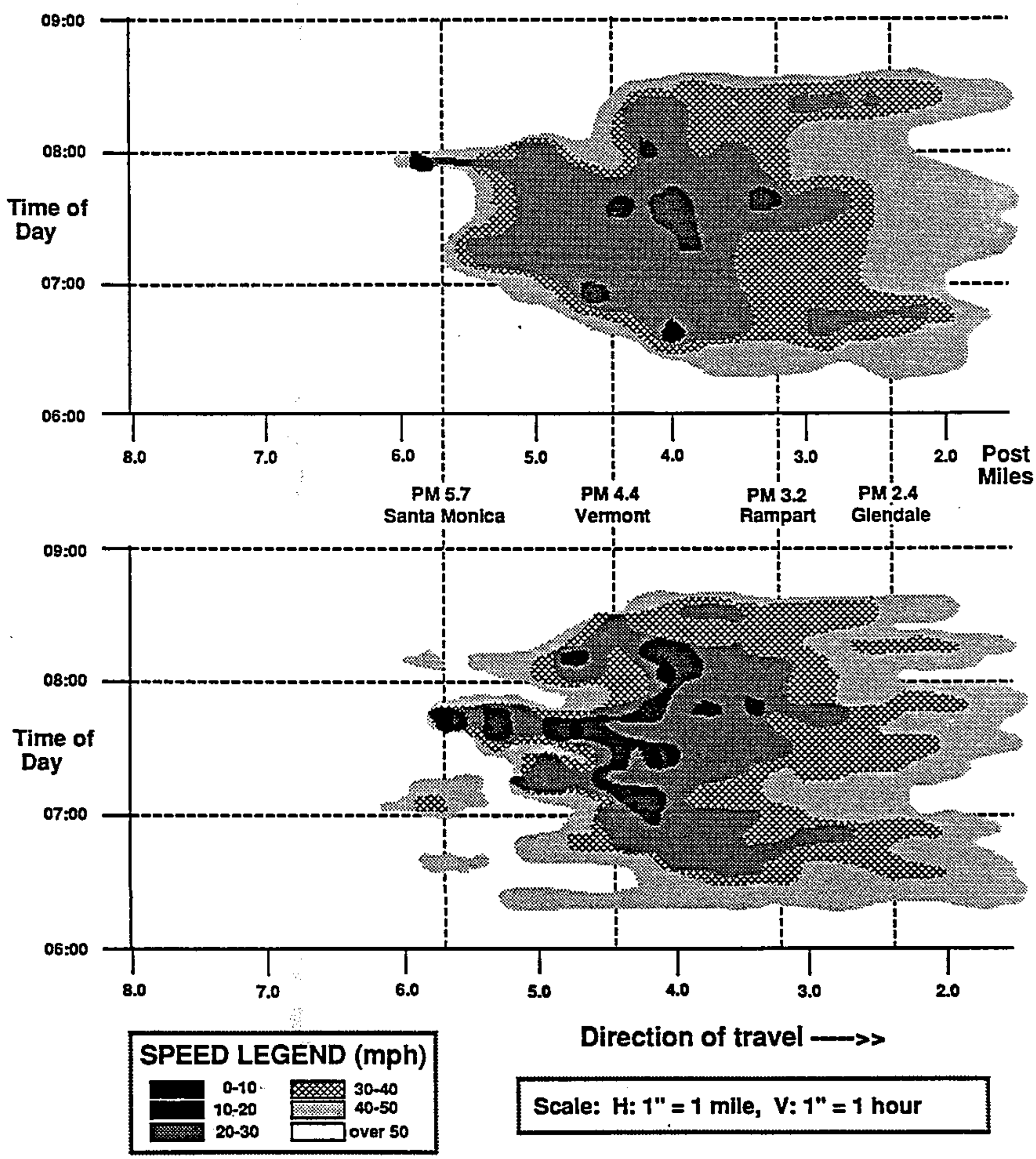


Speed Contour Plots

Southbound Hwy 101, Los Angeles

Morning

Data Dated: 05/20/85 - Upper Plot 05/21/85 - Lower Plot

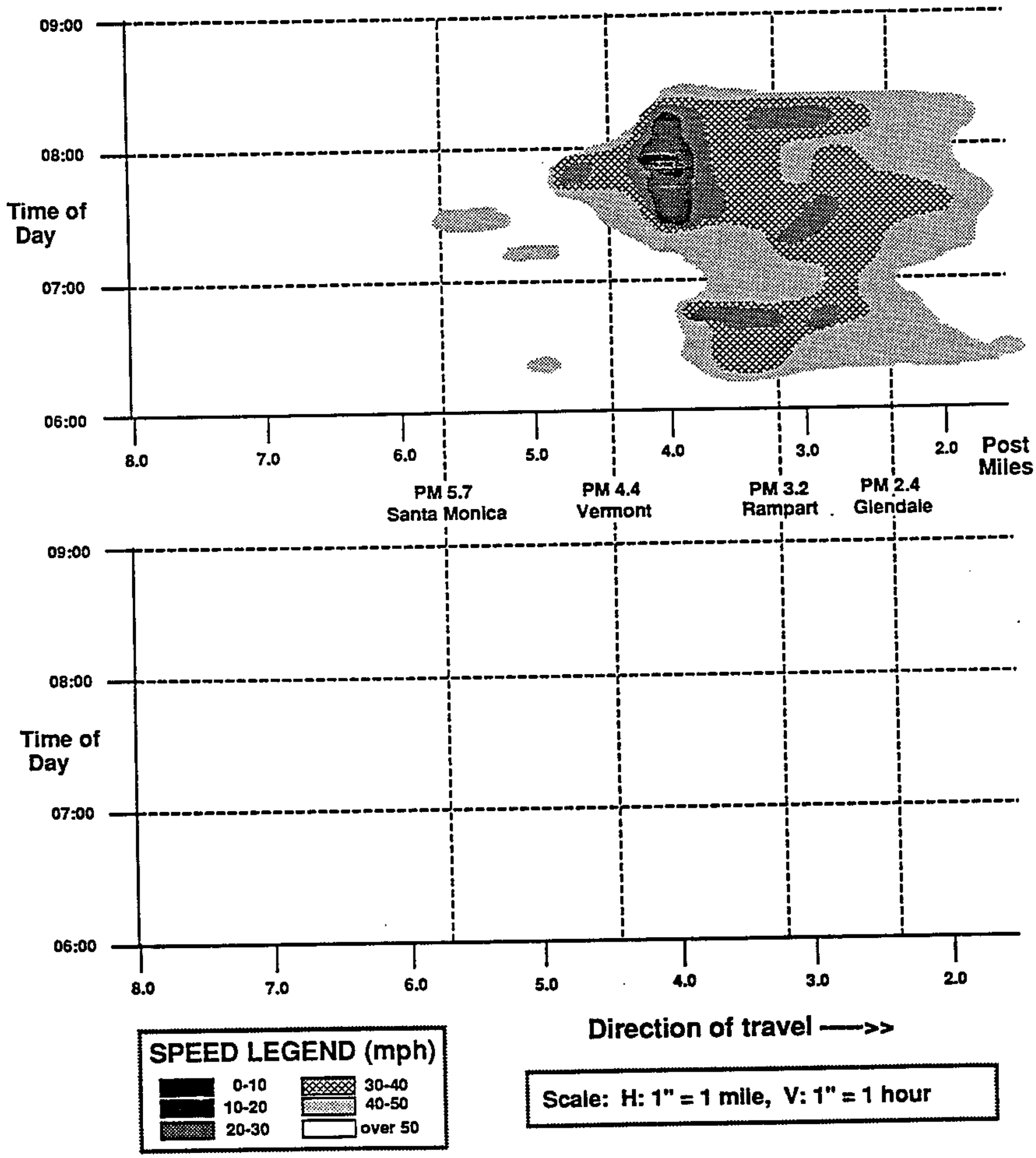


Speed Contour Plots

Southbound Hwy 101, Los Angeles

Morning

Data Dated: 05/24/85 - Upper Plot ##/##/## - Lower Plot

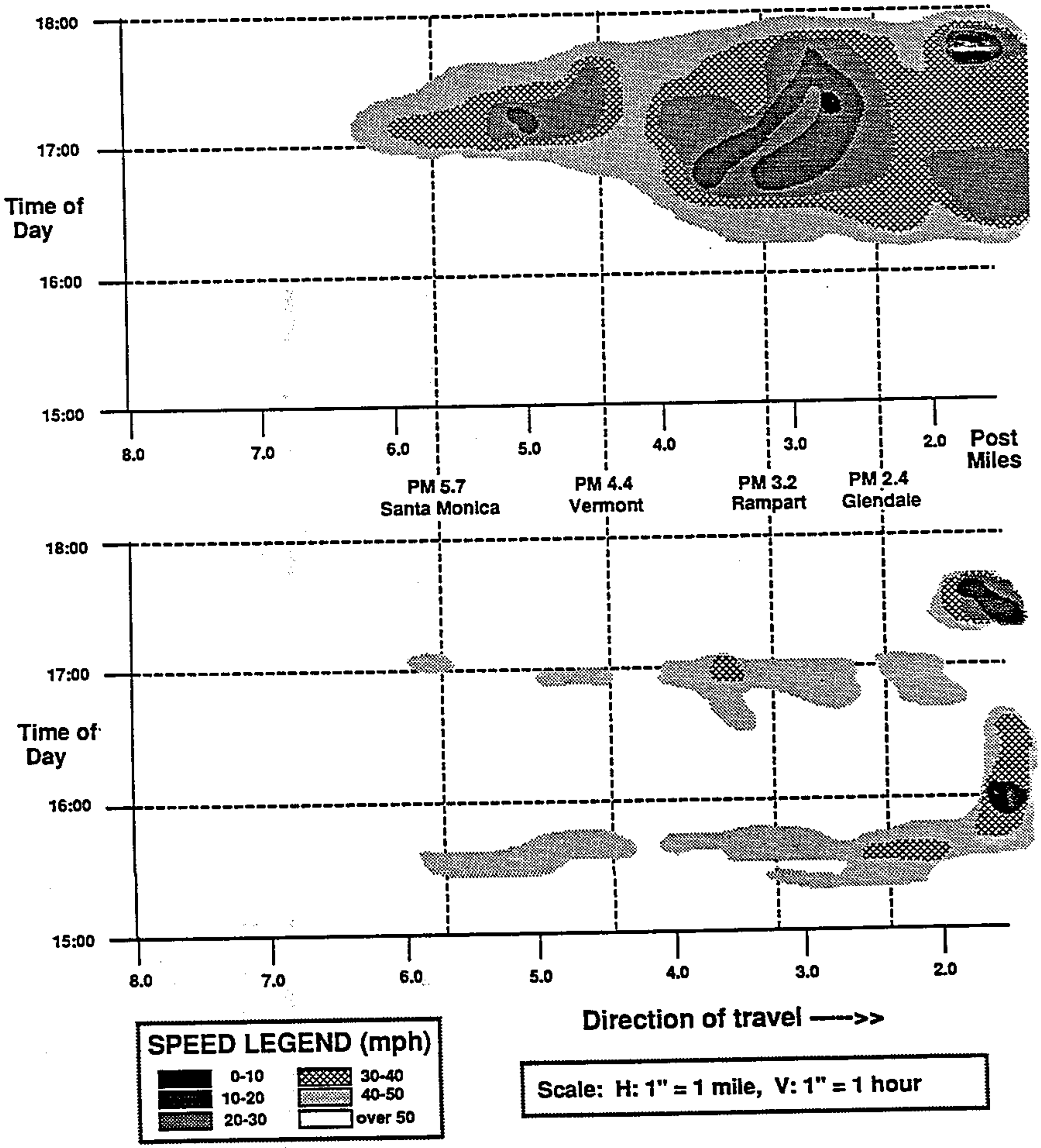


Speed Contour Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/13/85 - Upper Plot 05/14/85 - Lower Plot

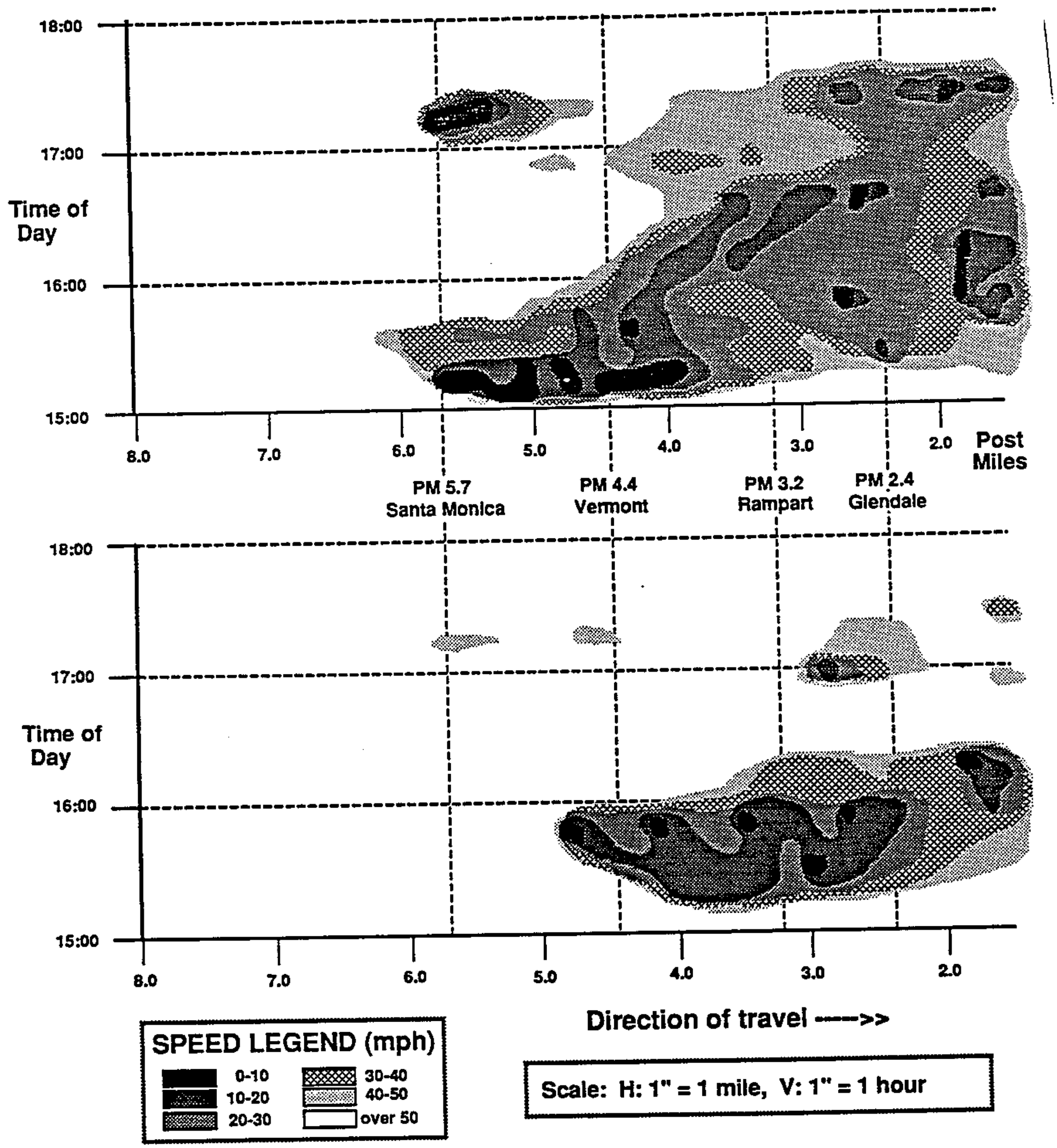


Speed Contour Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/15/85 - Upper Plot 05/16/85 - Lower Plot

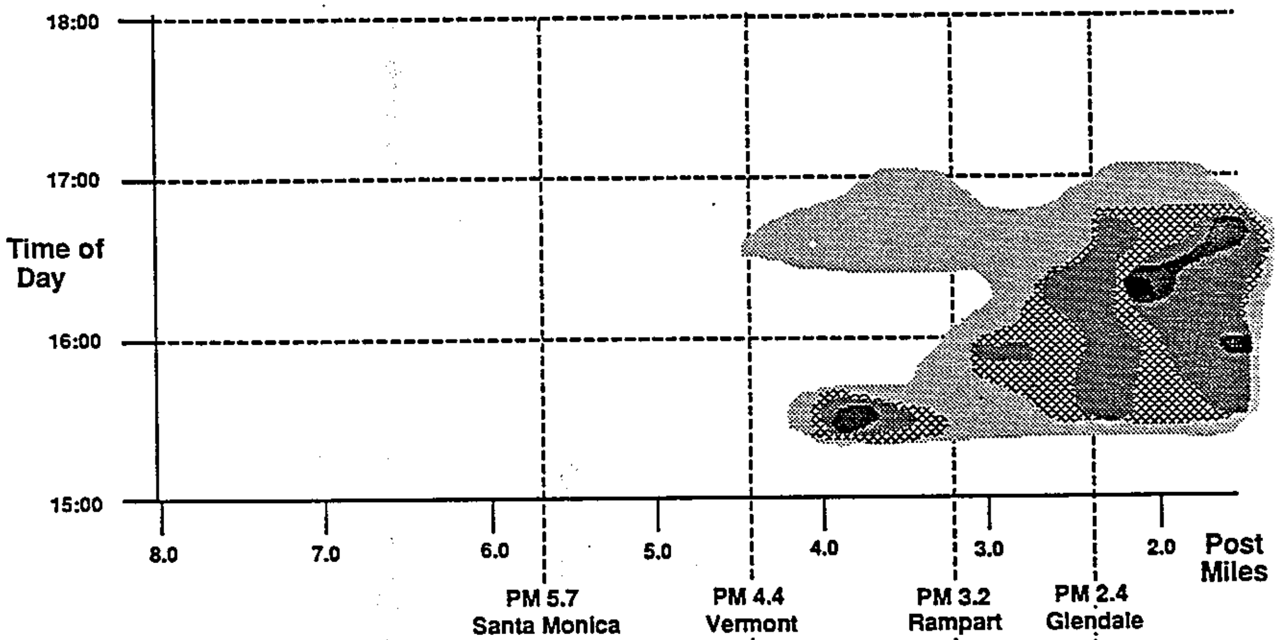


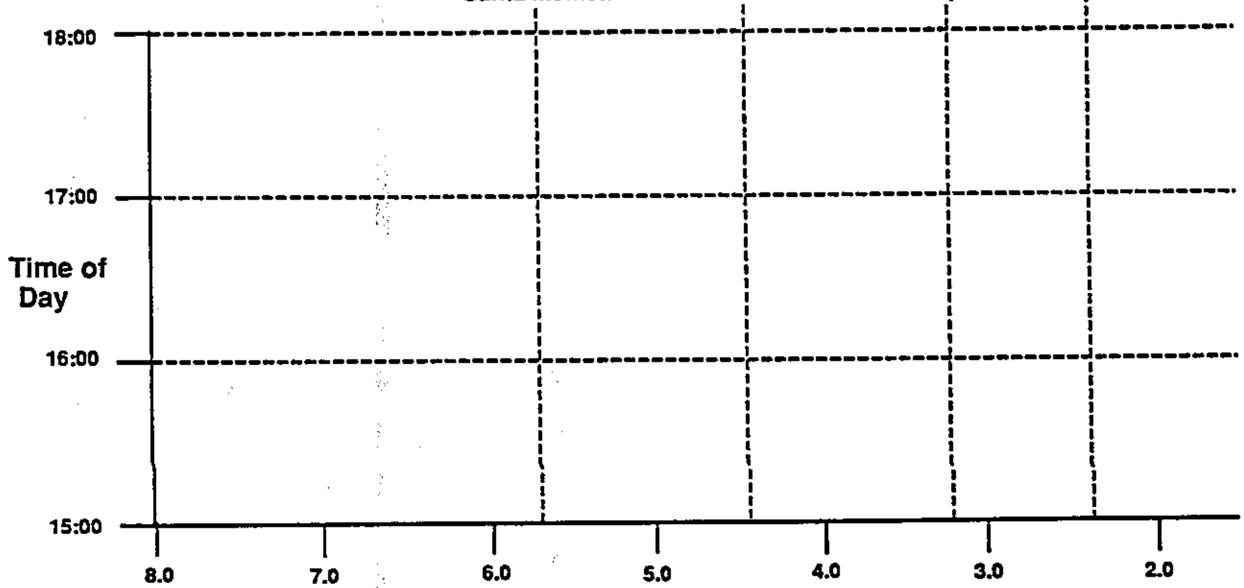
Speed Contour Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/17/85 - Upper Plot ##/##/## - Lower Plot





Direction of travel ---->>

SPEED LEGEND (mph)

0-10	30-40
10-20	40-50
20-30	over 50

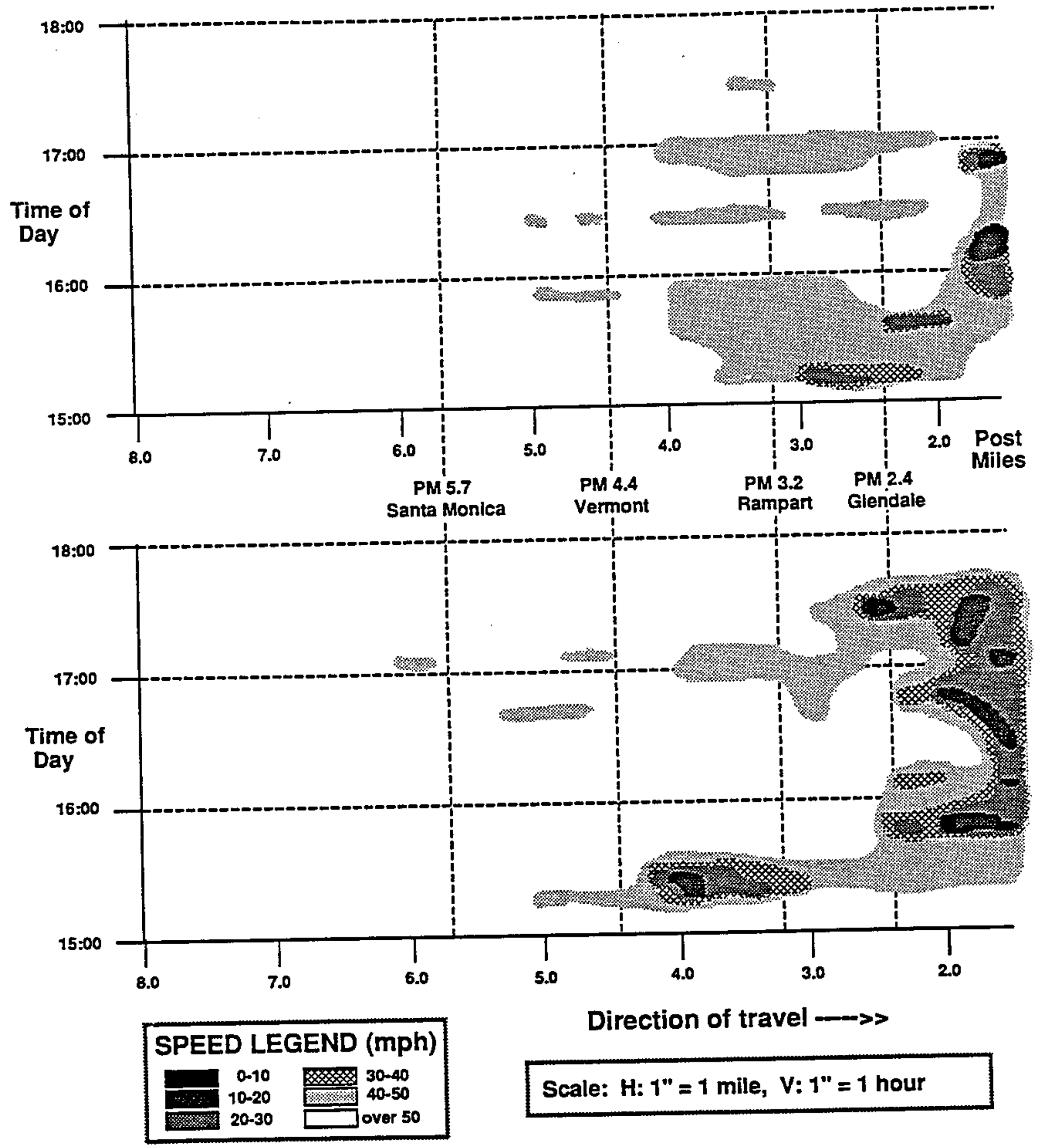
Scale: H: 1" = 1 mile, V: 1" = 1 hour

Speed Contour Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/20/85 - Upper Plot 05/21/85 - Lower Plot

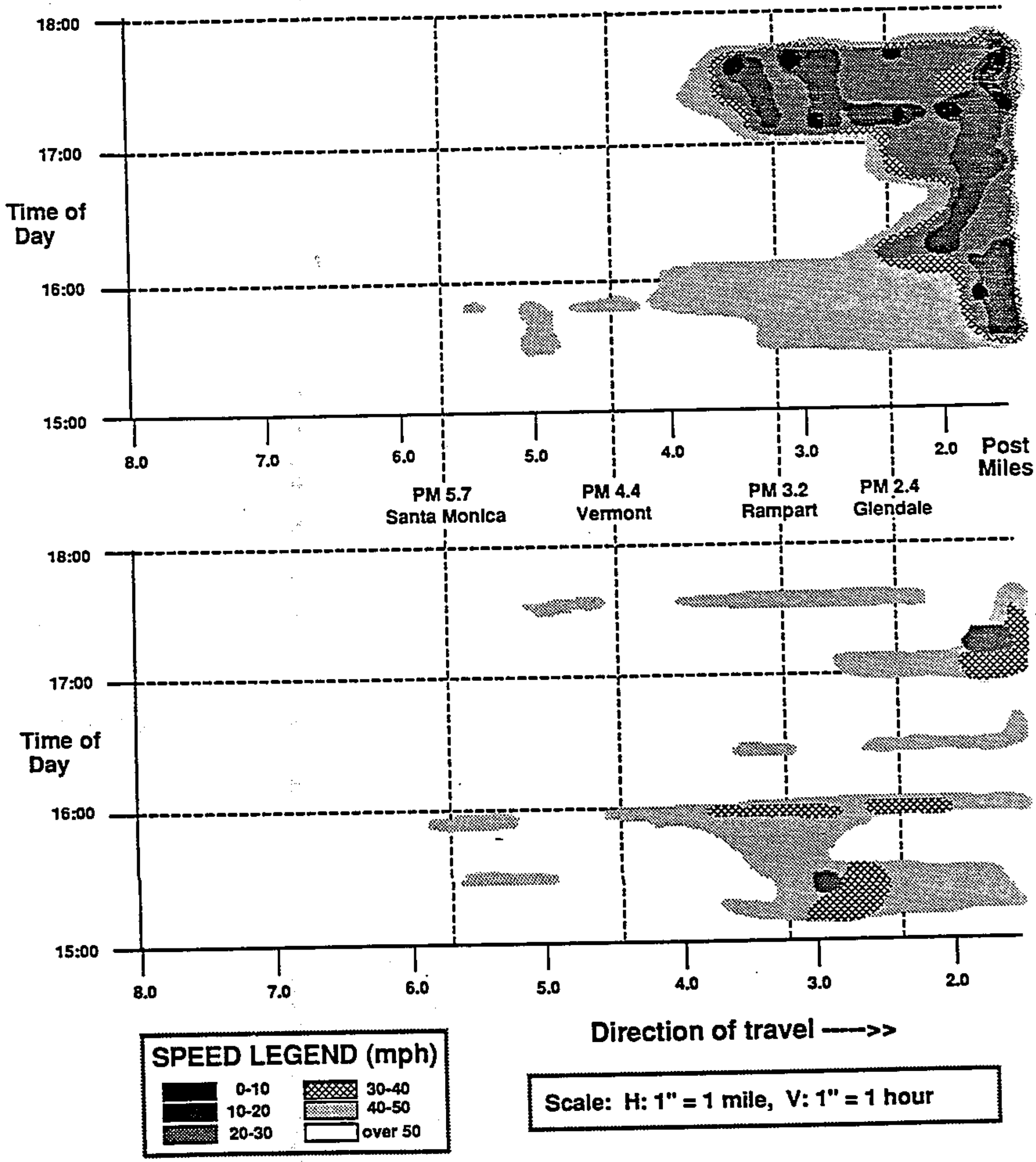


Speed Contour Plots

Southbound Hwy 101, Los Angeles

Evening

Data Dated: 05/22/85 - Upper Plot 05/23/85 - Lower Plot



APPENDIX E

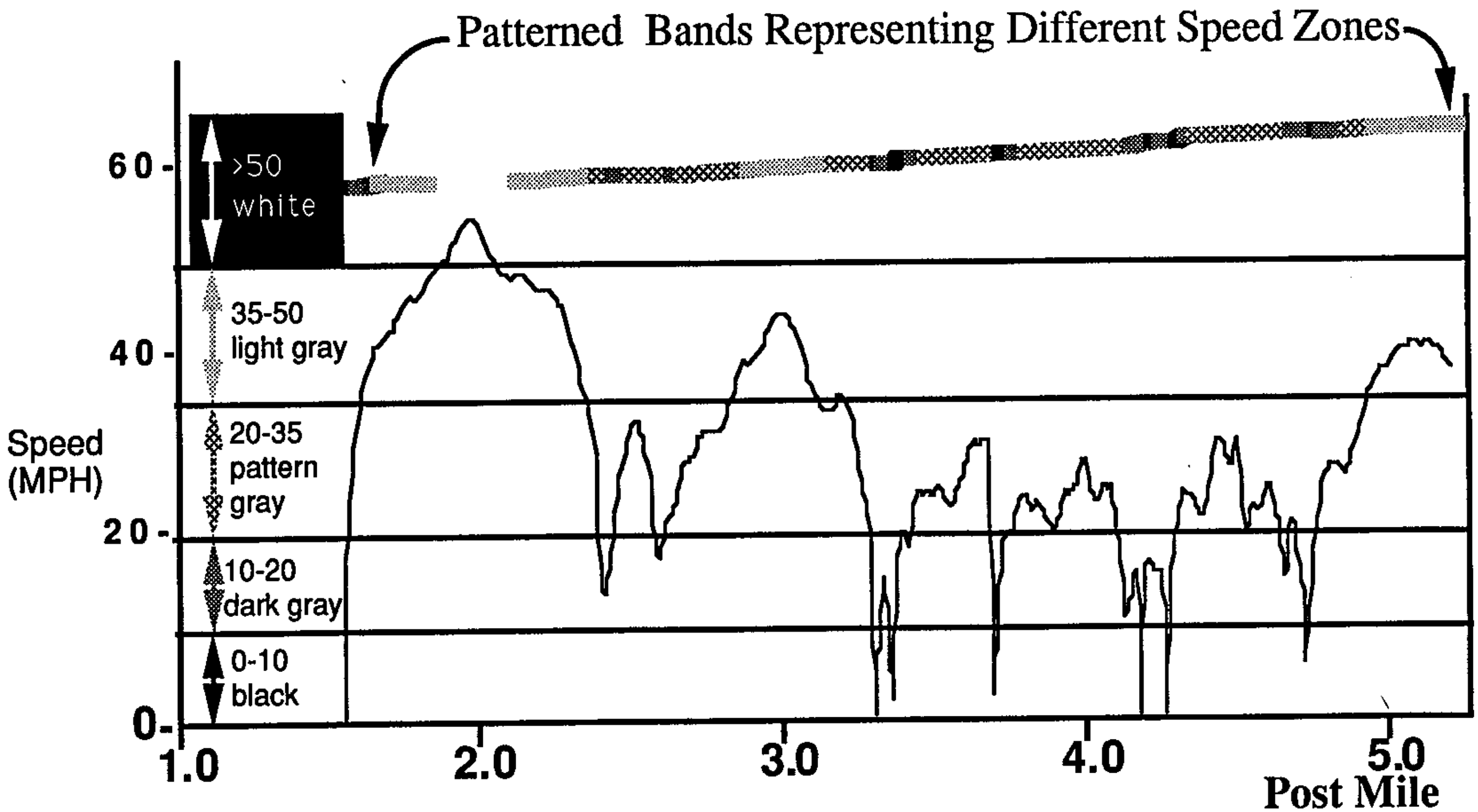
Contour Plot Generation

1) Speed Bands are generated from each run.

2) These bands are plotted on a time-distance axis.

3) A Graphic Editor is used to complete the plot.

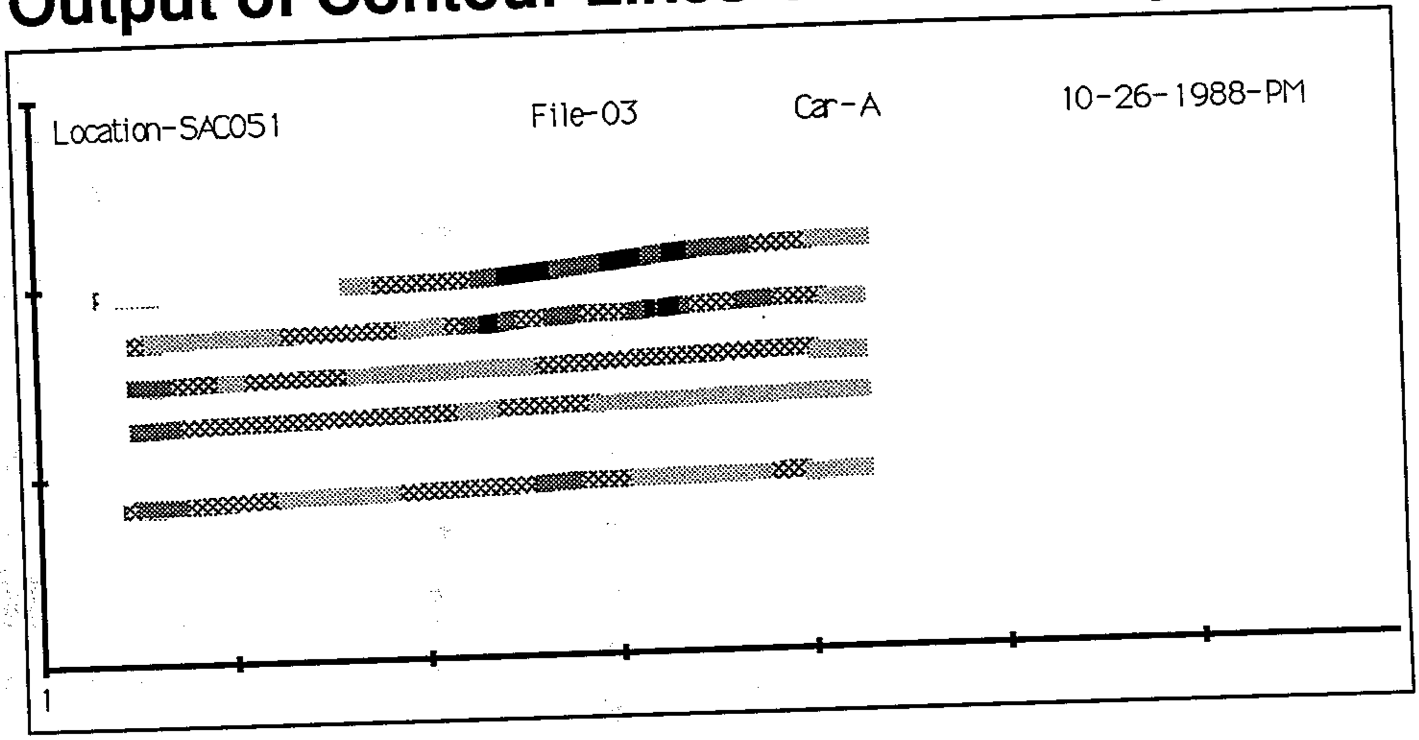
Speed Bands Generated From Tachograph Plots



Speed Bands are generated from each tachograph by associating a different color or pattern type to vehicle speed in each speed zone.

(A 10 sec. Moving Average of speed was used to reduce the effect of small speed fluctuations)

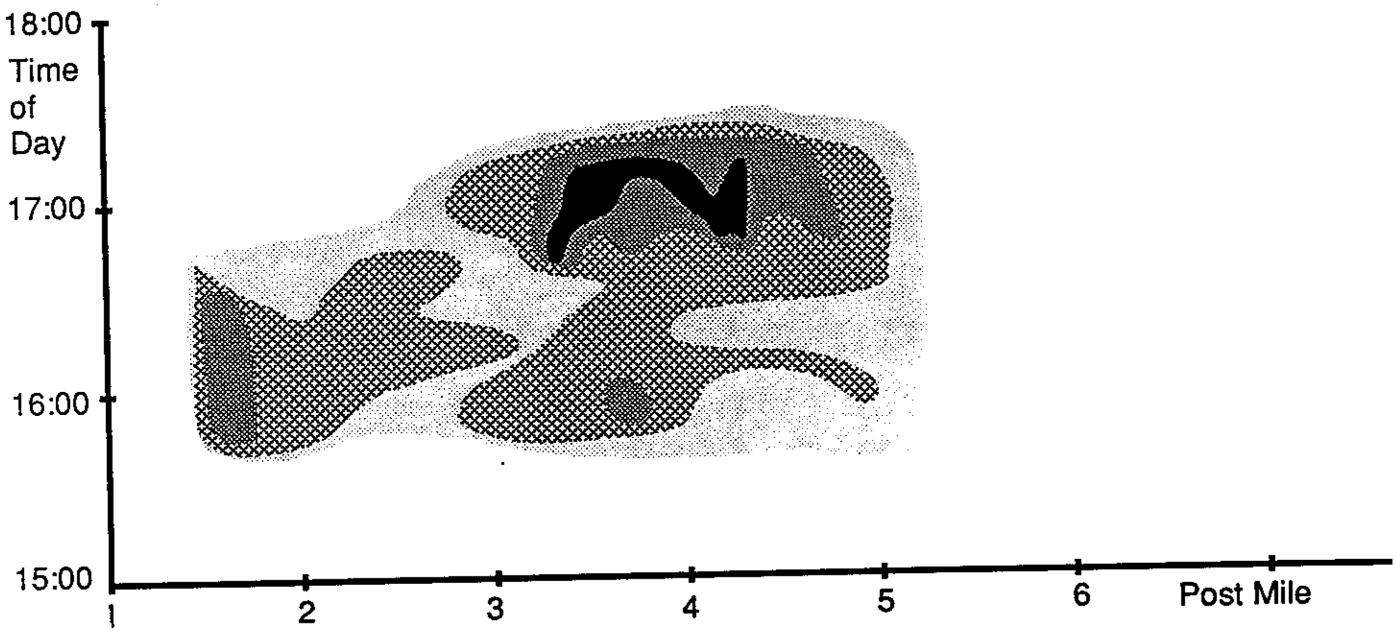
Output of Contour Lines Generated by CLOG



Speed bands are used as a template for the generation of the Contour Plot. The speeds between the speed bands are interpolated by filling them in with the appropriate patterns. More lines (runs) generate more accurate plots.

The Plot is completed in a Graphic Editor.

Contour Plot Generated from Speed Lines



Titles, Legend, Axis Identification, etc. are added in the Graphic Editor.

A completed plot is shown on the following page.

Speed Contour Plots

Southbound Hwy 101, Los Angeles
Morning

Data Dated: 05/14/85 - Upper Plot 05/15/85 - Lower Plot